TIGHT BINGING BOOK

EVOLUTION FOR JOHN

EVOLUTION FOR JOHN

BY

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Publishers' Note

THIS book, *Evolution for John,* is issued as a companion volume to Mr. Hilaire Belloc's *Economics for Helen.* In that work the name Helen was used for the knowledge-seeking reader, who nevertheless may well have been John. Similarly, *Evolution for John* will, it is anticipated, prove of equal value and interest to Helen.

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A DESCRIPTION OF EVOLUTION

CHAPTER I

WHAT JOHN THINKS ABOUT EVOLUTION

JOHN thinks evolution is "the doctrine that man is descended from monkeys," and he is so amused or so offended at this theory that his whole mind is occupied with it. His conception is ridiculously false. Until John discards that notion and makes a fresh start he will never understand the subject. Therefore anyone who tries to explain evolution to him will fail if he pays the least attention to the "monkey doctrine." In this book there is no reference to any ape-like creature and no discussion of the descent of man.

John thinks that evolution explains the origin of life. But no scientist pretends to know anything about the origin, and in this book nothing is said of a subject which is far beyond the reach of present human knowledge.

John thinks evolution has something to do with "progress"—that it announces some creed of an onward and upward movement toward perfection. Evolution is nothing of the sort; it does not venture into any speculation about the meaning of life or its final goal. In this book there is no doctrine of "progress" and no philosophical reasoning.

To the mind of John there is something mystical and awesome about "Evolution," especially if it is printed with a large *E*. The evolution in this book is usually printed with a small *e*, and means only the very plain scientific theory that every form of plant or animal that ever lived developed out of a previous form.

John guesses that evolution is true, but he rather

wishes it were not. He has a vague fear that the theory is materialistic and tends to weaken religious faith. But there is no ground for his fear. Recently a young Presbyterian minister said to me, "All our theology is now based on evolution." He represents the thought of many divinity schools to-day.

John suspects from head-lines in his newspaper that evolution is a debatable theory, that it is being overthrown every six months, and that it may be discarded before long. Yet there is no more chance that the theory will be disproved than there is that men will some time give up their belief that the earth is round; every reputable modern scientist believes in it as a matter of course. It is now an integral part of all general education and culture. To suppose that it may some day be abandoned is to live in intellectual barbarism.

To the common sense of John evolution appears probable. "But," he says, "it is not to be seen at work here and now, and so it looks dubious to me." When he has seen the "angel's motion picture" in Chapter XI. he will feel relieved.

John supposes that evolution is extremely difficult, so that he has small chance of ever finding out about it. For this supposition he is excusable. It is true that most scientific books are highly technical, and that evolution is based on several branches of science at once, and that each is hard to learn about, and that the combination of several in one theory is excessively complicated. Also it is true that, to the best of my knowledge, no simple explanation has ever been put into a volume. For twenty years I have tried to find some book in a popular style that I could place in the hands of young men who were curious to read about evolution, and I have longed to find such a treatment for myself, which would give me in a few hours an outline of the information that is hidden in the forbidding tomes of science. I have examined several

volumes that were said to be of this sort, but not one would serve my purpose. Librarians are constantly asked for "something simple about evolution," but they have to shake their heads sadly. Apparently the biologists know so much of the details that they cannot write a brief account of the whole theory. Not one of them has begun at the beginning of my ignorance and shown me, step by step, an outline of the whole. I see a lot of chapters about "Somatogenesis" and "Mendelism" and "Neo-Lamarckism," but I am lost in a wilderness of big words, and I haven't any sketch-map.

Probably most intelligent people have tried during the last quarter-century to learn something about a theory that has remodelled all the world's knowledge and profoundly affected its way of thinking. Recently I grew so desperate as to read a number of the standard works on evolution, and I was curious to see whether I could form a digest of the bewildering array of different branches of science to which all the authors have to appeal. I have written it out as if I were telling a friend about the knowledge that is so new and imperfect in my mind. It seems reckless to publish this. Yet the signs are that no professional scientist is ever going to attempt this job that so sorely needs to be done. Some amateur must try.

Evolution for John is not a proof of anything, because evolution has never been mathematically demonstrated. It is not an argument, because there is no sense in a layman's arguing for or against the entire body of learned men whose business it is to study organic life. It is merely an outline of what this body of scholars conceives to be the explanation of how living forms have developed. It begins at the beginning, with sketches of the facts, and gives descriptions of how scientists look at nature.

If you are not familiar with the history of scientific thought and not too eager to begin to read of evolution, spend a couple of minutes with the next paragraph,

which is about the theory that the earth moves. It is an excellent preparation for the chapters that follow.

The normal human brain, unfamiliar with the facts of astronomy, cannot conceive that the earth goes around the sun. A thousand generations of the most observant minds that earth could breed never suspected such an idea. Men learned to build great cities and to write poetry and to predict eclipses long before they ever questioned the apparent fact that the sun moves and the earth stands still. Twenty-five centuries ago Babylonian astronomers developed the notion that the earth might be a globe suspended in space, and a Greek philosopher three centuries later argued that the earth moved; but very few philosophers during the next twenty centuries could take this speculation seriously. They could not feel the earth move, and they could see the sun move. Yet the fantastic theory of the earth's movement lingered on in philosophical writings and was considerably discussed in Italy at the time when Columbus was preparing to sail west. Wild as this Pythagorean fancy seemed to most learned people, it appealed strongly to a Polish astronomer who was then studying in Italy. This genius, Copernicus, was equal to the superhuman task of fitting together facts and figures into a proof that the earth spins on its axis every day and travels around the sun every year. Yet because he made one wrong assumption, so that his explanation would not check with all the facts, most scholars continued to laugh at his topsy-turvy theory. During the next two hundred years his proofs carried conviction to very few astronomers. As late as 1800 there were many cultivated minds that believed it was irreligious to think of the earth's rotating and revolving.

With such extreme difficulty, after such prolonged controversy, can the human race accept a fact that is not directly apparent to the senses.

In a similar way there was current in the world for two thousand years a speculation that perhaps all animals

had developed from earlier and simpler forms, and those again from still earlier and fewer forms, and so on back to a beginning of all life in one lowly species. But this was sheer conjecture. Not until some genius could assemble a vast array of facts, clearly organised as an argument, would the scientists accept so curious a belief. This feat was performed in 1859, when Darwin's *Origin of Species* was published. So revolutionary a theory was bound to meet with opposition; but the argument was so thorough, and leading students of nature were so well prepared for it, that it soon convinced the scholarly world. To-day evolution is universally believed by scientists, and is regarded by zoologists and botanists as the fundamental truth on which all their investigations are based.

CHAPTER II

THE MYRIAD FORMS OF LIFE

How many kinds of animals does an ordinary person, intelligent but untrained, know about? We have an answer in the works of Aristotle, as observant and intellectual a man as ever lived. It is probable that he was not acquainted with more than five hundred [1] species; it is doubtful whether many persons ever see in the region where they live more than two hundred species. I once asked a capable boy, who had studied a little school zoology, how many kinds of beetles he thought there were in the world; his answer was, "About three in every country." The right answer is "about one hundred thousand well-defined species, plus a greater number of sub-species or varieties."

The contrast between these two estimates is a fair index to the experience that every naturalist has as he grows in knowledge. The few common forms that meet his eyes near his home increase continually as he sharpens his sight and lengthens the radius of his collecting. The revelation, I remember vividly, came to me in this fashion: I was set the school task of making a collection of twenty-five kinds of beetles; this seemed quite an undertaking, for I could not count above a dozen kinds that I knew. But as soon as I opened my eyes the new species appeared at every turn of the road, on every flower, under every bit of bark; the text-book by which I had to classify them named hundreds that I might never see; I learned

[1] Weismann says two hundred, but the index to the treatises on animals contains at least four hundred.

of a mathematics teacher who had gathered for his amusement five thousand species; I saw eighteen large volumes that were entirely devoted to the beetles of Central America; I found that the world was swarming with myriads of beetles in endless varieties.

Beetles, to be sure, are exceptionally numerous, but they are a fair illustration of the incredible number of varieties that you would learn about if you devoted a few years to the study of any family of animals or plants. This is the great preliminary fact that anyone must realise before he can enter upon an understanding of evolution. The first step of explanation for John must be to show him, in some kind of panoramic view, how the forms of life branch out into thousands and tens of thousands and hundreds of thousands of distinct species.

In this chapter we need not define formally what is meant by "species," except to say that it describes one sort of plant or animal that has some distinct difference in its anatomy from all other sorts, and that usually cannot cross or breed with other sorts. For example, cabbages and brussels sprouts are not called two different species, because they are so similar in structure; all our domestic dogs could be called one species. But the grizzly bear and the polar bear are distinct species; a pocket gopher from Kansas and one from California, though they look and act much alike, have to be classed as two distinct species. With such a free-and-easy notion of what a species is, we may now take a flight over the world of life. It will be most convenient to follow an order from the smallest and simplest plants to the higher animals.

Wherever life is abundant in the world, every foot of space teems with invisible plants called bacteria. Some of these are so small as to be beyond the reach of the most powerful microscope, and are guessed at only by their effects in producing disease. Some are so short that fifty thousand of them if placed end to

end would reach only one inch, and these are two or three times as large as the germ that is supposed to produce infantile paralysis. Bacteria multiply in such excessive numbers that the mind reels before the figures. For instance, it is estimated that each human being is daily assisted in the digestion of his food by several trillions of these organisms. Nor must we forget that every individual of the trillions is a highly complex being which digests food by intricate chemical processes and which reproduces itself by a mechanism that is so subtle and complicated as to be beyond comprehension. Bacteria are everywhere, living in the most varied ways. They (and closely related fungi) cause all the decay in the world and produce most of the contagious diseases. Upward of fourteen hundred species have been described.

There are ten thousand[1] species of microscopical algæ that produce slime, and six thousand more that produce a muddy deposit, the exquisite "diatoms." There are four thousand species of sea mosses and kelp. There are more than fifty thousand species of those fungi that we know as toadstools and mildews and smuts.

It would be of little use to continue to set down rows of astonishing figures, for the mind cannot conceive them nor retain them. But it is of the greatest use to appreciate, if only dimly, something of the extent to which lowly forms of plants are diversified. Even so brief a glimpse as this at the wide expanse of life sets the mind to wondering, "How did it all come about? Why should there be so many different ways of living?"

How many kinds of mosses have you ever heard of? If we had never seen but ten kinds, we could rest with the supposition that they were originally created so; but when we learn that there are sixteen thousand species of these inconspicuous growths, and that the

[1] The numbers of botanical species are taken from Ganong's admirable *Textbook of Botany for Colleges.*

more common of the species have varieties that grade off insensibly into varieties of another species, then we cannot be content with any such guess at the cause. The more a botanist becomes familiar with the countless varieties of plants the more certain he feels that he is dealing with some sort of continuous growth of the whole system of organisations. A few dozen different ferns would never have excited a Wallace or a Darwin to cudgel his brains for an interpretation of nature; but the four thousand five hundred species that botanists now know might well cause an inquisitive mind to lie awake at night.

All told, there are about one hundred thousand species of this lower division of plants. Of the higher division, the flowering plants, there are more than one hundred and thirty thousand species. Some of the items that make up the total are five thousand grasses, one thousand palms, two thousand lilies, seven thousand orchids, one thousand two hundred cactuses.

More significant than mere numbers is the way in which plants unlike in appearance are found to be alike in their anatomy and way of growing, so that kinds which are very dissimilar in all outward appearance are found to have inwardly a decided family resemblance. Thus elm trees, fig trees, nettles and hops are found to have such a similarity in their flowers that they belong together. The figs include such apparently unlike plants as the rubber tree, the banyan and a vine-like parasite. In another great group the botanists have been obliged to lump together geraniums, flax, oranges, mahogany and castor beans, because they are similar in their ways of propagating. The scientists have no desire to do queer things; they would much prefer to say that rubber trees and milk-weeds are alike because of their milky sap; simplicity has always been their aim. But nature has made it impossible for them to find any simple way of classifying. It is as if she had strung the most diverse forms on one thread of structure, and had then so looped

and tangled the thread that the botanists are taxed to their wits' ends to straighten it out in anything like orderly sequence. When a man has laboured for thirty years at this effort to untangle related forms he comes to think of plant life as a labyrinth, and he demands a clue. What will guide him? His work would be easier if he could discover that all the criss-crossing forms were originally created as distinct kinds of organisms, but the opposite conviction is continually thrust upon him—namely, that these forms are a jungle of variation, that all plant life has for ever been altering in character, putting out changes here, there and everywhere.

The puzzle would not amount to much if a species were always a species—if, for example, a certain kind of pine tree were everywhere the same. But within any species there may be endless variations, some of them amounting to striking differences. A grizzly bear, for instance, would seem to be very different from a cinnamon bear; but grizzlies have been found that shade by slight degrees of colour and size toward cinnamon bears, and a series of cinnamon bears could be arranged that shade off in colour and size to meet the series of grizzlies. No sharp line can be drawn, and hence some scientists have called them all one species.

Another illustration of the endless variegation within a species is a certain small grass-like plant, *Draba verna*; when samples of this are gathered from different parts of the world it is found that there are many distinct types—no less than two hundred have been counted, each of which will breed true to itself. Each of these types, the so-called "varieties," might be called a species. And any naturalist who cares to cultivate the varieties can breed new ones; he can, as it were, watch the plant branching out into new forms. So with wheat; one acute observer counted in a field no less than twenty-three varieties which would, if separated and cultivated by themselves, continue to produce the twenty-three types

of plants. A botanist in Amsterdam once counted seven hundred varieties of hyacinths. It is estimated that American florists have caused fifty species of irises to branch out into one thousand five hundred distinct varieties; that they have developed as many forms of roses; and that there have been produced in the gardens of the world no less than eight thousand varieties of roses. So endless are these variations that botanists have no power to tabulate them; one of the most famous, the Dutchman, de Vries, says of hawkweeds, "Thousands of forms may be cultivated side by side in botanical gardens, exhibiting undoubted differentiating features, and reproducing themselves truly by seed."

What shall a naturalist conclude after he has spent studious decades in watching these ceaseless fluctuations of countless forms of plant life? What shall he think when he takes stock of this medley of life, this unmapped chaos of contradictions and relationships? He has no chart or compass until he adopts the evolution theory; with it he can always steer a course.

The same remark applies to the zoologist. If men had never known of more than five hundred kinds of animals, they would not have realised that chaos exists and would have laughed at evolution. Down to 1700 the knowledge of the diversity of life was so meagre that naturalists did not recognise any mystery. Even after Linnæus had been compiling data for thirty years—and no more industrious, capable classifier ever lived—he could learn of hardly more than four thousand[1] species; he would never have felt impelled to solve a mystery in 1758. But by 1858 the situation was entirely different; Agassiz then calculated that one hundred and thirty thousand species were listed, and many discerning zoologists began to fear that they were all at sea. Within

[1] Most of the following figures are the estimates of Professor H. S. Pratt of Haverford, in *Science*, March 22nd, 1912.

thirty years from that date the count had more than doubled; and twenty-five years later had almost doubled again—that is, a conservative count had reached 522,000 species. If by that time (1912) the zoologists had not had the aid of the evolution theory, they would have been swamped by the mounting billows of species and sub-species.

To say that in 1912 there were listed in scientific libraries 522,000 species of animals is like speaking of millions of pounds in a public debt—we cannot comprehend such a tremendous sum. No more can we have a comprehension of the numbers of animals until we dwell upon a few of the details. One of the smallest items illuminates the whole subject strikingly: fifty years ago only thirty species of deep-sea fishes had been seen; now there have been dredged up and accurately described more than one thousand species. Linnæus, the great father of classification, whose fame is still bright, could count only forty-one species of worms; there must be 8,000 known to-day. We now know of 2,500 kinds of sponges, 16,000 of spiders, 3,500 of reptiles, 61,000 of molluscs. Collectors have penetrated the wildest quarters of the globe, have braved the desert heat and the arctic ice, have searched the mountains above and the ocean below; everywhere they have discovered new species by dozens and hundreds. Whereas Linnæus could count only 444 kinds of birds, we know of over 13,000. He listed only 183 mammals; at present we have accounts of some 3,500.

These figures were compiled by Professor Pratt in 1911, and may be ten per cent. under the totals that could be reckoned to-day. If any of the figures are too high, we may be assured that before many years they will be too low; for they are being augmented almost daily. L. O. Howard, one of the greatest entomologists, has said that the number of insects now known may ultimately be multiplied by ten. Men who,

like him, have spent a lifetime amid the rising tide of numbers would yawn at our little lists of the hundreds of thousands; for they do not think in terms of arithmetic, but in one term—of a flood of varied life.

And this flood of life now in the world is only a small pool when compared with the ocean of forms that have, during the long history of the world, risen and flourished and become extinct.[1] The geologists are familiar with limitless reaches of changing life that stretch through the millions of years of the geologic ages, glimpses of which may be seen in the fossils. Even the fragments of this ancient history, when pieced together in a list, reached, twenty years ago, the respectable aggregate of eighty thousand species of vanished life. The great naturalist Wallace believed that in the whole past history of extinct forms of animals there "*must* have been thirty or forty times as many species as are now living." He guessed that *probably* there have been on the earth in all its different periods "many hundred times as many species of plants and animals as now exist."

So boundless, to the gaze of a scientist, is the realm of life which we amateurs have tried to skim over in one brief chapter.

[1] The long record of the prehistoric life of the earth, perhaps covering five hundred million years, is outlined in Chapter XI. It furnishes stronger evidence than the study of the forms now living.

CHAPTER III

THE TANGLED WEB OF LIFE

THERE is nothing baffling about mere numbers of species. If the naturalists had never been confronted with any problem more puzzling than half a million or a hundred million species, they would never have been driven to seek out an evolution theory. The previous chapter gave several indications of the real mystery: the tangle of forms. Only a lifetime of experience would give a partial conception of the endless series of kinds that shade gradually into other series of kinds. In this chapter we can do no more than view, as from an aeroplane, distantly, a few of the thousands of bewildering facts known intimately by scientists.

In the previous chapter we got very little suggestion of any bewilderment. We saw neat packets of "one thousand two hundred kinds," of "three thousand five hundred kinds," of "sixty-one thousand kinds." The inference was that a biologist could tell two distinct species as easily as a stamp collector can decide that two bits of printed paper are not duplicates.

The fact is just the contrary. Professors Pratt and Ganong would be the first to admit that no count of species can be made, that their lists represent only the roughest approximations to a set of balances of opinions. Until a reader understands that statement he is not on his way to a comprehension of evolution—any more than a detective could find a criminal before he knew what the crime was.

What is life? The more we study it the less able we are to give a definition. If an invisible bacterium

is an individual plant, why is not a white corpuscle in our blood an independent animal? And if a white corpuscle is a separate creature, how shall we draw the line between it and a cell in our muscles? If these self-propagating cells of our flesh are animals, why is each self-propagating cell of a leaf not a plant? We cannot tell where individual life begins.

As soon as we pass upward from this doubtful region of cells at the basis of all life, we are at a loss to know the difference between the lowest plants (Protophyta) and the lowest animals (Protozoa). The voice of science can only admit that "no hard-and-fast line can be drawn around Protozoa to distinguish them from Protophyta." It declares that "the formal distinctions between the animal and the vegetable kingdoms have vanished, and in their place we have an intimate, unbroken continuity."

So at the very beginning of any examination of the world of life it appears that all is confusion. The naturalists could never arrive at any understanding of this vast tangle until they found some one principle that would account for all the variety of the strands and for all the interweaving of them. All our observation of nature shows that nothing ever happens by chance, that every object we see was fashioned by undeviating law. Hence any naturalist in his senses must suppose that every least filament in the web, every variation of form, every continuous series of forms, became what it is by the operation of some fixed, unvarying forces. Just as our minds are obliged to think that there must be definite causes for rainbows and wireless telegraphy and tides and fires, so we take it for granted that the various forms of life are not the result of a hodge-podge of unaccountable accidents. Much less can any reverent person nowadays credit the idea that a whimsical Creator amused Himself and befooled His human children by devising a lawless welter of freaks.

The devout and sensible scientists never tolerated

such an idea. With one accord they have always assumed that there is some definite method of creation, and they have done their best to discover it.

After 1700 their efforts were based on a certain assumption—a very natural one and very useful. This theory was that all animals were arranged on a "scale of nature," from the low and simple forms to the high and complex. Each degree on this scale was a small but sudden step upward from one kind—called a "species"—to the next higher kind. Thus each species was sharply marked off from the one below and the one above; it was a distinct type of life that had always been what it now is, and that would never be anything else.

The "scale of nature" hypothesis stood the test of experience fairly well in the eighteenth century for classifying four thousand species; it still applies after a fashion; for the species that we observe in nature *seem* fixed.

An account of what the word "species" signified in 1830, and of the controversy about it, is the easiest entrance to an understanding of the evolution theory. Some readers will wish, first, to see a display of the term in its setting in the system of classification that has been used for the last two centuries. For their convenience the following numbered paragraphs are inserted to show the graduated divisions, from large to small. This is not a review of technicalities, but is an approach to the heart of the subject.

The nature of classification. To begin with, what are the scientists about, what is their purpose, when they "classify"? They are only doing what we all have to do in our private affairs when we arrange *or sort out* a lot of articles that are in confusion. No business office can keep five thousand letters in the same order in which the postman brought them; they must be sorted—that is, classified—alphabetically or by their

subject-matter. A carpenter must classify his tools and nails and screws, else he could never put his hand on what he needs; a school must classify its students as failing, passing, doing fairly, or doing excellently; if the people in a city were not classified by names and streets all general business would come to a standstill. So the scientists would be all at sixes and sevens unless they carefully classified their huge stores of facts. One example will bring this home: thirty-five years ago the manuscript of the catalogue of plants kept at Kew Gardens weighed a ton.

1. *Kingdom.* A vast labour the classification has been, and is still very incomplete. A glimpse at the nature of it can be had most easily by noticing how the first ancient classifier went to work. He began, as any shrewd man would after some observing and meditating, by dividing all life into two "kingdoms," vegetable and animal; and the scientists still follow this primary division.

For the first subdivision of animals Aristotle found that he could make two great groups, according as they had or did not have a backbone. Among those with a backbone he naturally made sub-groups of those that walk on four legs, those that walk on two legs, and those that live in the water. Then his troubles began; for a man walks on two legs, but is unlike all the birds in not being covered with feathers. Classification is a task that demands the highest analytical skill and patience. To this day the zoologists are agitated about the shortcomings and contradictions of their system of sorting into orderly groups all the known kinds of animals.

2. *Phylum.* With their elaborate details we have no concern, but we do need to know their principal terms. In beginning an arrangement of animal life they first try to put together in large groups those sorts that are similar in some general way; for example, all the backboned animals are grouped together into

a "phylum." In another great phylum are lumped together all such "jointed" animals as insects and lobsters.

3. *Class.* Within each huge phylum many subdivisions must be made; for example, all the lobsters and crabs and barnacles are put into one "class," all the spiders into a second class, all the insects into a third.

4. *Order.* Insects are such a vast horde of dissimilar forms that they must be subdivided many times before there will be any practical classification; they are sorted into twenty "orders." One of these orders includes all the beetles.

5. *Family.* It is clear that classification has only begun. The order is divided into great groups called "families." The largest family of the beetles, for example, is the snouted weevils.

6. *Genus.* This family, like every normal one in the plant or animal kingdoms, is subdivided into groups, each of which is called a "genus" (plural *genera*). One genus of weevils, named *Anthonomus,* includes many sorts that make a specialty of living in buds and pods; its members are spread over the whole globe. Classification is always that same operation of making narrower and narrower divisions of groups whose members are somewhat alike, sorting out those that have closest resemblance into smaller and more homogeneous groups, and then again sorting each smaller group into sections that are most alike.

7. *Species.* Such a subdivision of a genus is called a "species." A species is the last complete stage of the sorting process; it is such a narrow division that all the members of it bear a close resemblance to one another and can usually mate together; whereas the members of two well-defined species can rarely produce fertile offspring. *Anthonomus* contains one world-famous species, *grandis,* which has destroyed billions of

pounds' worth of property for the cotton-growers—the boll weevil.

8. *Variety*. It often happens that within one species there are many somewhat different forms, which can be accurately defined and which breed as true to type as distinct species; these are called "varieties."

When we consider that such an exhibit of classification, though it extends through eight paragraphs, does not represent an outline of the scheme of even four thousand animals, we have a faint suggestion of the interminable maze of nature, and of the struggle which the eighteenth-century naturalists had.

This struggle centred on one point—on the theory that species are unchangeable. The reader must centre his attention on the same point, for it is the approach to the whole subject. A species, as the eighteenth-century classifiers conceived it, was a certain kind of plant or animal that never had been and never could be different. Linnæus believed that a species was an unchanged and unchangeable unit of life. His own words were: "There are just so many species as in the beginning the Infinite Being created."

If this had been true the course of natural science would have been smooth. The zoologists would simply have had to detect these eternal kinds of life and count them up as astronomers have counted the stars. Great was their amazement to discover, long before 1800, that they could not agree on how to distinguish. They all wanted to agree; they all took it for granted that agreement would be possible. But with the years the disputes increased. Even Linnæus had qualms when he found how often a dividing-line was difficult or even impossible to draw. By 1800 a Frenchman (Lamarck) had denied that such divisions could ever be made successfully, because as the stores of facts rapidly increased he saw the tangled web grow ever more tangled. He put the case thus in the very year of Darwin's birth,

1809: "The supposition generally believed—that organisms are arranged in 'species' that are always distinguishable by invariable characteristics, and that the existence of those species is as ancient as nature itself—was established at a time when men had not observed enough and when the natural sciences as yet hardly existed. It is always belied in the eyes of those who have seen much, who have long attended to nature, and who have studied with profit the large and full collections of our Museum."

Around the conception of species the battle raged. In France and Germany and England there were plenty of learned men ready to abandon the idea that a species was a fixed fact of nature. But if they had done so, where would they have found themselves? Floating in a fog of philosophy. It might be all very well for a reckless, imaginative Frenchman to abandon facts and speculate about all life as a continuous stream of forms that changed into one another. But that was to deny their own senses, for they could see a multitude of fixed species, and Lamarck could not show them one that changed into something else. Why should they give the lie to their own eyesight? They were like Romans who were asked to believe that the sun stood still and the earth moved. They decided—and quite sensibly—not to follow such vagaries of philosophy until some tangible evidence was forthcoming. It did not come. No one could find any proof for Lamarck's fancy. By 1850 it was considered unscientific and foolish to discuss any evolution theory. The fixity theory was more firmly established than ever.

The scientists were, nevertheless, perpetually uneasy, at a loss, discordant among themselves. For they could not mark the limits of the species that they believed in. It was a curious dilemma. If a man believed that species were variable he was beyond the pale of realities; but if he believed that species were fixed he could not lay

his hand on the realities. Either way he was lost and baffled in the tangled maze of living forms.

"What is a species, anyhow?" was the constant query. Darwin often reveals in his letters what all scientists felt, but could not well give vent to in their formal publications. He wrote in 1849, when trying to classify the barnacles: "I cannot at present tell the least which of two species all writers have meant by the common *Anatifera lævis.* Literally, not one species is properly defined." In the same year he wrote to a great botanist: "I often feel wearied with the work, and cannot help sometimes asking myself what is the good of spending a week or a fortnight in ascertaining that certain just perceptible differences blend together and constitute varieties and not species. . . . I have just finished two species which possess [*i.e.*, in the different works of reference] seven generic and twenty-four specific names!" Seven years later he wrote again: "In naturalists' minds resemblance is everything, and in some resemblance seems to go for nothing; in some sterility is an unfailing test, but with others it is not worth a farthing. It all comes, I believe, from trying to define the undefinable."

Huxley thus describes a bit of the dialogue when, as a young man, he had his first interview with Darwin: "I expressed my belief in the sharpness of the lines of demarcation between natural groups with all the confidence of youth and imperfect knowledge. The humorous smile which accompanied his gentle answer, that 'Such is not altogether my view,' long haunted and puzzled me."

No wonder that Darwin smiled, for he was familiar with facts like these: "As soon as these three forms, which had previously been ranked as three distinct genera, were known to be sometimes produced on the same plant, they were immediately considered as varieties; and now I have been able to show that they are male, female, and hermaphrodite forms of the same species."

Wallace pictures the situation vividly in this sentence: "All students were so impressed with the belief in the reality and permanence of species, that endless labour was bestowed on the attempt to distinguish them—a task whose hopelessness may be inferred from the fact that, even in the well-known British flora, one authority describes sixty-two species of brambles and roses, another of equal eminence only ten species of the same group."

The first authority had "split" the roses into sixty-two species; the second had "lumped" them into only ten. This case is typical. The same tendency is as strong as ever to-day: if a naturalist is keenly interested in noting slight differences he will find many species and be a "splitter"; if his mind works on the other tack he will be a "lumper."

In a recent study[1] of a genus of crickets the author tells us that six species have been commonly described, that one man lumped these into two, that another man lumped them into two by a different grouping, and that the author thinks there is only one species.

If we should search the classifications of the ants, as made by all the splitters, we might count six thousand species; if we took the records of the lumpers, and selected the lowest list from each, we might have no more than two thousand.

Any amount of similar evidence could be cited to show that a species is essentially an opinion. If a very careful man makes a prolonged study of a certain genus, and if succeeding students think well of his judgments, his opinions stand as named species; if his judgments do not stand the test, they are set aside by the next student. Illustrations like this from the *Britannica* article on wolves can be found very frequently in common books of reference: "These differences have given rise to a supposed multiplicity of species. . . . But it is

[1] F. E. Lutz, *Carnegie Publication* 101.

doubtful whether these should be regarded as more than local varieties." Indeed, all the efforts of all the authorities to assort wolves and dogs and foxes and jackals have failed to produce any generally accepted scheme of species.

A pretty demonstration of the whole species puzzle has been exhibited in a museum. A circle of fifteen tiger beetles is so arranged that the distinctive markings of one species, shown fully in the first specimen, are slightly different in the second, somewhat more different in the third, and so on, until when we have gone the round we find that the fifteenth specimen, next to the first, has the markings of another species.

Truly the works of nature appear as cycles that merge into other cycles, and these loops are combined in a tangled web of life.

CHAPTER IV

THE VARIED MODES OF LIFE

WHEN I, with my untrained eyes, pay any attention to plants they seem to be very regular, uniform things. A buttercup seems like all the other buttercups; an acorn seems to produce the same kind of oak that it fell from; a house-fly is always of the same size and has parents and children that are exactly like itself; a sea-gull never mates with a hawk; everywhere I go there are a lot of buttercups and flies and hawks and ants that are just the same as the ones I have seen before; an oyster is never an eel. So far as I ever noticed all forms of life are well separated, distinctive, uniform. I never see any puzzle or any need of worrying about classifying.

And so long as I do not see any puzzling irregularity I cannot have any interest in evolution or take any stock in it. Every naturalist would have been as indifferent as I am if he had always remained as ignorant as I am. No person will see any sense in evolution until he knows at least a little bit of the endless confusion and criss-crossing and interlacing of the kinds and modes of life of plants and animals.

So it is time to describe a few of the puzzles that every biologist meets with. If you find this chapter somewhat bewildering you are on the road to understanding; for you can then see, in some slight measure, what the scientist's problem is. This chapter does not explain anything. It takes you to a maze of facts and says, "Look at this, and this, and this. See what the scientist has had to explore and find a clue to. Notice that the facts are interlaced and perplexing."

In this and the following chapters we are going to take the course that Darwin's mind covered in his twenty-five years of effort to solve the mystery. It is as if we, in an express train, whizzed at a mile a minute through the jungles where he had to hack his pioneer way foot by foot. As you glance at the few dozen illustrations in this chapter try to imagine what they would be like if they were multiplied by a thousand, and if your life depended on working out some theory that would bring them all into a neat and orderly arrangement.

1. *Groups are Big and Little, Flourishing and Dying.*

If I say to a man who has never pondered on the mystery of life, "This yellow-flowered weed belongs to a genus (*Senecio*) in which there are 2,300[1] species," he may think of a greenhouse where there are 2,300 flower-pots—or he may think of nothing. He does not feel that there is any puzzle about it. "Lots of kinds of weeds?" he replies. "I should say so. Weeds flourish everywhere." But ask him to imagine how a botanist understands the statement. To the botanist there is no such thing as the difference between a "weed" and a cultivated plant. He knows them all alike as plants that have to fight for a living in the soil. When he hears of a genus of 2,300 species he recognises a group that is extraordinarily hardy, that has spread over wide reaches of territory, that has fought its way to victory in many climates, and that has branched into 2,300 different ways of making conquests in battles against other plants. He admires it as a mighty and successful kind of organism. He sees it is an adaptable, ever-varying form that flourishes like a very fountain of changeable life.

[1] Gager, *Heredity and Evolution in Plants*. Most of the figures given in this chapter are taken from older works of reference; hence they are generally understated, though in a few instances they will be larger than those shown in some recent taxonomic arrangement.

Show a botanist the opposite kind of picture: "Here is a Chinese tree (the gingko) which is a separate genus all by itself; there is only one species of it." Then he is struck as by a sight of a dying race. He is puzzled as he contrasts it with a group of 2,300 species. Why should it remain so stolid and meagre while another race goes victoriously forth in a myriad of guises? One genus seems to sport in lavish, youthful strength; the other appears to be dying. In an orderly universe what should make races come and go?

A zoologist meets the same mysteries of the big and the little groups, the flourishing and the dying. A genus of squirrels in Borneo and another in India have only one species each; of the genus of pigmy squirrels there are a few species; of the striped ground-squirrels there are more; and of the tree-squirrels there are dozens—large and small, gaudy and plain—all over the world. Similar contrasts could be cited without end. The genus of hares is everywhere—in the foggy north of Scotland, in Brazil, in the Himalayas—over-running all countries with its thirty species; whereas the genus of camels is domesticated in a small region and has only two species.

The same contrast of numbers and strength is seen in the "families" of plants and animals. Ordinarily a family is a large group embracing several or several dozen genera. In the sunflower family there are one hundred and fifty genera, and in the great families of animals there may be as many. But some forms of life are so peculiar that they must be made a family all by themselves; thus there is now living on the earth only one genus of the rhinoceros family.

Those words "now living on the earth" give a hint of the depth of the mystery. The study of fossils shows that forms have waxed and waned through the millions of years of the geologic ages. *There used to be* many genera in the rhinoceros family. A long acquaintance with

this flow and ebb of life arouses a suspicion that a large and a small family, a large and a small genus, are not permanencies, but temporary fluctuations; and such a thought is exciting to any scientist who is trying to discover nature's secret. A certain genus of sequoias is now limited to two species on one strip of coast, though some millions of years ago it flourished in many species from ocean to ocean. Why should this ancient group have dwindled almost to extinction while the genus of pines was increasing to seventy species that triumphantly made their way to every part of the north temperate zone?

Nor is the mere fact of large and small, flourishing and dying, the most striking feature of what naturalists learn. Their curiosity is more aroused when they find that a chart of their classifications resembles a tree. If a certain order of animals branches into three families, two will probably be small side-branches and one will be like the continuation of the main trunk. If this dominant form divides into twelve genera, one genus will be very small, ten will be moderate in size, and the twelfth will be the large and typical group. It is this dominant twelfth genus that will ramify into a hundred species, and most of the hundred will show more vitality, be more numerous, and tend more to split into varieties, than the species of the eleven small genera. And of those hundred more lusty species there will probably be three that are decidedly more numerous and common, spreading into more varieties, than any of the others. A botanist expects a map of an order to look like the trunk of a tree, which grows upward in a main stem, the principal family; this family continues in the largest branch, the principal genus; and this genus continues upward in a few sub-branches, the principal species.

2. *Varied Sizes in One Group*

Among the rattlesnakes there is a species of which a full-sized adult is only eighteen inches long; another

species furnishes specimens four times that length. Among the frogs, of the one genus *Rana*, there is a species (*goliath*, from Western Africa) which weighs ten times as much as any frog that I ever caught for bait. In India there is a rat with a body that is over two feet long. The palæontologists have found in the family of horses a genus that was only a foot high. In a systematic, man-made world the clams would all be about three inches long; in the world as it is clams range in size from under that standard all the way up to *gigas*, which may be forty-three inches long and weigh nearly six hundred pounds.

There is a parasitic animal so small that it is barely visible when shown in a good light against a contrasting background, and another that is two inches long, armed and armoured in a terrific manner for the capture of tarantulas; yet both are wasps. A similar case is the pigmy deer, the dikdik of East Africa, which is only a foot high; it is quite unlike the little mouse deer of Asia, but *is* closely related to the great Eland deer which may weigh more than half a ton.

When a visitor has strolled through a menagerie and a museum he is impressed by these freakish variations of size; he wonders why nature has sprouted out into all these deviations from a standard.

3. *Varied Developments*

The boy Darwin, like the rest of us, thought that a frog was just a frog; it was a leaping land-and-water animal that lived and looked like all the other frogs. How many readers of this book know that some frogs never enter the water except to breed; that one species burrows for its home; that another lives in trees and has a membrane with which it becomes a kind of flying frog; that another species builds nests among the bushes above the water; that another is hairy; that most species have teeth only in the upper jaw, while some have teeth

in both jaws, and others have no teeth ; that one species in the Solomon Islands has a horn ?

We stay-at-homes, who spend our time with bridge and business and novels, never know how, in the most uniform and monotonous genus, nature has modelled surprising species. She is perfectly varied in the most contradictory ways. No person can credit evolution until he sees something of what naturalists are involved in. No uniformity can ever be expected ; no rule can ever be guaranteed.

It is a rule, for instance, that animals eat plants and that plants draw food from the soil ; and that rule holds for a hundred thousand species, and the next hundred thousand, and the next, and the next. But there is an exception. There are one hundred and fifty species of plants that eat animals. One, in Georgia, has hinged leaves that close on a fly, digest him, and open for the next fly. Another, in Australia, develops some of its leaves into cups that entrap insects. The American pitcher-plant, of an entirely different order, makes for itself a much more elaborate trap, that is always open for insects and digests them by dozens. In the Malay Islands there are species of still another order that put a lid on their pitchers.

Rather bewildering all this, when we consider that these similar and very peculiar devices are found in different *orders* of plants on all the continents. A fanciful naturalist might guess that since the youngest rocks were made several very different sorts of plants had learned to eat meat ; for no such fossil plant has ever been found. It was a mere fancy, an utterly wild and unwelcome one, to any steady mind in 1830.

We human beings are apt to suppose that agriculture and slavery are a pride and a shame peculiar to the human race. But go to the ant. There is a tropical species which cultivates the fibrous growths of a kind of toadstool ; they have learned to cut off the spore-bearing branches,

so as not to let the plant breed and destroy itself. Many kinds of ants keep plant lice, as a sort of cattle, for their sweet juices. Some ants have grown so used to being served by enslaved ants that they are powerless to feed themselves and would perish without the servants.

The more we see of animals the greater grows our wonder at their varied developments.

4. *Varied Relationships*

Most of us remember the mental shock we received when we first learned that whales and porpoises are not fishes, but warm-blooded, air-breathing mammals, that suckle their young on the cold ocean waves, and that would drown as surely as an elephant if they could not breathe air. Similar contradictions in classification are the stock-in-trade of every zoologist.

There is an opossum-like creature in Australia, not a foot long, which has a decidedly greenish colour —the only mammal known which has fur thus tinged. In Tasmania there is a creature that looks like a wolf, that seems as different from an opossum as a tiger does from a rabbit; yet it is allied to the opossums, and is not a wolf at all. The duckbill, which looks like a beaver and is covered with thick fur, has a horny bill like a duck and lays eggs.

Plants furnish many examples of criss-cross relationships. Staid old peach trees, with only peach-tree ancestors, have more than a few times been known to send out a sporting branch that bore nectarines. The botanist cannot draw any boundary-line between peaches and almonds; for a small, hard, seedling peach is very like a green almond in appearance and structure; from these inferior peaches "we may pass by small transitions through clingstones of poor quality to our best and most melting kinds." On the other hand an apricot, which seems so like a peach, is by some botanists classed in a different genus, is commonly grown on the stocks of plum

trees, and—quite unlike the peach—will grow true from seeds.

No matter-of-fact human brain could ever invent the freakish relationships that are to be found in plant life. Who would have thought of a partnership between two classes? A botanist who had dreamed that plants "learned" to catch insects might believe that his dream was confirmed when he investigated lichens: here are four thousand different kinds which are compounds of two different classes of plants, fungi and algæ. The fungi and algæ enter into a very close partnership and provide nourishment for each other. The truths of botany are stranger than any fiction could be.

5. *Varied Ways of Propagating*

Occasionally there is an intelligent person, with opinions about evolution, who supposes that winged moths eat clothes; he does not know that the moth has for a mouth only a delicate tube with which she could not injure a cobweb. Yet this same intelligent person knows in a general way that there are voracious caterpillars, with powerful jaws, which spin cocoons, in which they become dead-looking pupæ, and from which they emerge as moths with a slender, sucking proboscis in place of the former jaws. Most insects go through these three stages of life. A moth or a fly comes into its third stage full-sized and usually leads a life that is entirely different from its first stage.

The double life is common among smaller animals, in the most extraordinary ways. Many disease-causing parasites live their first stage in one animal and their second in another. They may live rather harmlessly in spiders or mosquitos or squirrels or pigs; then when, by most diverse and remarkable means, they reach a second victim—a cow or a person—their second stage causes a virulent disease like bubonic plague or sleeping-sickness or malaria. Barnacles, after living as free-

swimming, soft-bodied creatures, spend the second and longer part of their life-cycle dwelling quietly in a shell.

Some animals reproduce by throwing off buds; some have male and female parts in one organism; in some cases the male individual is a mere minute parasite; some marine species seem to be male or female according to the accidents of their life. Plant lice breed for a long series of generations as females only, without any pairing; then comes a generation that contains males, and there is pairing of the sexes. Among the plants are to be seen all manner of combinations: one sex only, two sexes in one plant that mate in that plant, two sexes in each plant that can mate only with the sexes of another plant, only one sex in each plant.

Why should nature, that stern and steadfast mother, thus toy with ways of propagating that seem so wantonly varied?

6. *Varied Heredity*

We have been taught that like breeds like. We know that a grain of mustard seed will produce a mustard plant, that an eagle's egg will yield an eagle. Surely, if there is any way in which we might suppose that nature is unvaried, it is in this matter of like producing like. If I walk through a patch of wild roses they look alike to me; the ones I see in Devon seem like the ones in Fife.

But a florist, who has eyes to see, detects the differences. He knows that roses are very unlike, fluctuating in size and tint and odour. Put him into a field, and he will cull you out a dozen unlike ones, will plant their seeds, will cull again from the second generation those that are more unlike, will continue for several generations, and will then show you a "new" rose, such as the sun probably never looked on before.

To my dull eyes the sheep in a flock are very much alike, but a shepherd knows them individually and calls them by name. Probably I could not tell one ant from

another if I studied them under a microscope, but a Huber knows them apart as if they were children of the neighbourhood; he names them and recognises their mental peculiarities. Like never does beget precisely its like.

And yet it is obviously the rule of nature that like *tends* to produce like; ordinarily, an animal is like its parents, as they resemble theirs, and so on back through ten generations. If Huber had lived a thousand years earlier he would have seen similar ants with the same individualities. Indeed, the tendency to produce similarity seems strongly preponderant; for if the florist's artificially selected roses were put back into a state of nature they would soon recur to the ancient type. If crossings were made between two of our artificial domestic breeds of fowl the offspring may show a strong tendency to revert toward the natural form that they had several thousand years ago when they were wild on the slopes of the Himalayas. Like does tend to produce like.

This contradiction in heredity is an illustration of all the paradoxes woven into a web that hid the secret of nature from the prying eyes of science. It was this woof of contradiction and variation that young Darwin had before his eyes when, like Siegfried before the wall of flame, he girded himself to penetrate the veil. He indulged in no such heroics about matching his intellect against the secret of the ages; but, after he had been around the world observing the varied forms of life, dedicated himself to the struggle in these simple words: "It occurred to me that something might perhaps be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it." Not till he had spent twenty-two years in accumulating did he allow himself to publish. Then his *Origin of Species* opened a wide gate to knowledge, through which all men might walk and view a most remarkable revelation.

CHAPTER V

THE JUNGLE OF ADAPTATIONS

In the last three chapters we have been taking glimpses at the mazes of life, and in this chapter we shall continue to do the same. There is no explanation here. We are going to look at a mystery, one at which men have always marvelled and for which they have spun various theories out of their imaginations—the devices that enable living creatures to obtain a living. its

Every plant and animal has it own way of succeeding in its struggle to live, is fitted for getting food and competing with its rivals by a peculiar anatomy and a particular set of instincts. All such adjustments for the fight of life are called "adaptations." Their enormous number and variety, in an endless luxuriance of competing series of devices, are only feebly indicated when likened to a tropical jungle.

The woodpecker is adapted for preying upon insects that live under the bark of trees: two of its long sharp toes grow backward and two forward, thus forming an instrument for grappling the surface of a free; its tail-feathers are spiked to give a purchase for the toes and are like a spring to help the hammering operations; the bill is a beautiful chisel; the skull is, unlike that of any other bird, so contrived that the rapid succession of resounding blows on the wood can be delivered without racking the head to pieces. This bird is adapted for its life-work. It could not live by wading or by searching for carrion or by diving in water, but is contrived to be a highly successful hammerer. Even a heedless mind is struck by this arrangement. Even a dull mind naturally asks, "How did it all come about?"

Every child knows of the adaptations of animals for fighting and for defence: the rhinoceros is armed with terrific horns; the wasp has a most elaborate sting and poison gland; a Brazilian eel is equipped with an electric battery that can give powerful shocks; the skunk and the pinacate beetle emit offensive odours; the sword-fish is armed with a combination battering-ram and spear that can pierce the planking of ships. Whence came these adaptations?

Nature-books picture the adaptations of the camel, which is fitted for its desert life by the thick soft cushions on its feet, by the hump where food is stored, by the tanks in its body where water is stored, by its power to digest dry shrubs, by its power to close its nose when a sandstorm is raging. So complete is the adjustment of these parts of his body that the beast can carry a rider two hundred and fifty miles across the sand in five days without a drink. How were all these devices assembled in such a partnership for enabling camels to live in the desert?

The equipment of some animals is so extraordinary that a description sounds like a fairy story. There is a small fish, living in the utter darkness two miles below the surface of the ocean, which makes its own light that shines out through port-holes along its sides, and which sees through eyes that are perched on the end of long stiff tentacles. There are birds that hatch out eggs when the temperature is twenty below zero. There is a Malay plant with a blossom three feet wide which, when it is ready to be fertilised, makes an odour like tainted meat, and thus attracts the flies that will bring the needed pollen from other similar plants. These examples are not extreme. Stranger ones can be found in books that treat of the wonders of nature—for example, Fabre's accounts of insects.

If you ask a Malay savage why the big red blossom has this queer power of making a bad odour, he may tell you a myth of how some angry spirit designed it. Ask

an Englishman who has spent his life in arm-chairs, and he will say that the blossom was designed that way—that 's all there is to it.

But ask a man who has long been curious about the odours of flowers, who knows all about these adaptations, and he will shake his head and talk like this: "It 's too much for me. If there were in the world only thirty-four odours of flowers, and if each were an adaptation peculiar in itself, I could let it go at that and bother my head no more about it. But the longer a man trains his nose in this study of mine the more he finds out that there is no sharp distinction between one smell and the next. No flower has any special adaptation of odour, but everyone blends into its place in the whole long array of all the odours.

"It 's like a spectrum of colours—you know, the rainbow band that is made when a beam of sunlight goes through a prism. If I stick a pin here in the band and another pin half an inch farther up I can see the difference between the orange and the yellow colours. But if I start at the first pin and move my eye along only one thirty-second of an inch at a time I 'm not sure whether I can see any difference; the change is so gradual and blended.

"That 's the way it is with the flowers. If I made up a row of fifty thousand species, starting at the bottom with our friend from Malay and putting next above him one from Brazil that isn't quite so offensive, and on top of that an Abyssinian specimen a trifle less rank, and so on and so on, until I reached no odour at all, and then continued my graduated scale on up through very slight odours, to violets, and up to mignonette, and on up to tuberoses, then I should have a continuous spectrum of odours, all grading into one another. And that is not the strangest fact. The plants in my arrangement for odours would not correspond to the botanist's classification, but would cut across his groupings like the shaft of a

mine through all the orderly layers of rock. The more you learn about odours, the more they seem like one continuously varying stream of adaptation."

If you ask a student of birds, "How were a woodpecker's adaptations made?" he will smile at the ignorance behind the question. To him you are like a child who has heard about Franklin's kite and wants an explanation of lightning in words of one syllable. "Yes," he answers, "the woodpecker's feet and his spiked tail are beautifully designed for life on a tree—if you never leave Europe. But in Argentina and Africa there are woodpeckers with all this equipment which never light on a tree. Their beautiful adaptations are utilised for making nests in clay banks!"

He pauses to see what effect his sarcasm has produced on us. We catch our breath and murmur something like, "Well, we thought that a clear case of design like this——"

"Oh, you *thought*," he interrupts. Now he is irritated. "When you learn about some little quaint adaptation you *think* about it. You *think* how ingeniously nature contrived it. You *think* that nature is a humorous artisan, like a Nuremberg toymaker, sitting in her shop and designing animals by fixed patterns. You ought to be ashamed of yourself. What business have you to insult nature and your own common sense by talking as if there were only a fixed number of varieties of birds, and as if a woodpecker were always a woodpecker, and as if you had named a patented, machine-made brand of invariable anatomy when you say *woodpecker*.

"I tell you," he continues, his voice rising, "that you have no conception of what you say when you let that word *woodpecker* slip off your tongue. There are three hundred species of them, of all sorts, and their adaptations blend into one another so that they seem like a crooked current of adjustment, sometimes running smoothly and sometimes dammed and thrust out of its course; and

they criss-cross one another so that it passes the skill of man to classify the freaks of adjustment. Perhaps you are so observant that you know a red Colaptes from a yellow one. What would you have done if you had been with me a few years ago when I tried to disentangle the mixtures of these two strikingly different species? What would you guess about adaptations if you found that a certain species was all duly fitted out with spikes on its tail, but that it couldn't use them because the tail-feathers were too limber? Perhaps you would judge that Dame Nature was having some fun at the expense of the poor bird, or that she made an error that time. You talk about the toes. Why, any quantity of birds, quite outside the woodpecker family, have that same arrangement of two toes before and two behind; but one genus of woodpeckers is *not* so constructed. What's more, some of these 'yoke-toed' birds have the first and fourth toes turned back, while others have the first and second turned back. What do you *think* about those adaptations?

"The fact is that nature is the big central force, and it is more powerful and more remote from our poor thoughts than we can conceive. It doesn't do any petty tinkering in a shop. It works in just an opposite way. in a great and simple and dignified way.

"The way nature makes adaptations is—well, it's hard for us humans, on our little island of the universe to take in. You never will take it in till you are familiar with the facts, the facts, the countless facts. Go ahead for a while with your adaptations. They are facts, and you need to know them. But don't injure your dazzled brain by thinking much about them at present. After you've seen a few samples of the gorgeous truths, turn back to pebbles on the beach. Educate yourself gradually in a few simple facts. It's the only way if you want to understand that the sun of adaptation does not revolve around the little globe of the human brain."

If we should interview all the zoologists and botanists in the country we should receive the same kind of advice. Let 's skim around the world and gather a few impressions of this blinding mystery.

High in the Andes Mountains, where the streams run violently among the boulders, lives a little thrush that is adapted for gaining a livelihood in the water. Its dense and fibrous feathers keep the body from being wet; it clings to stones at the bottom of the current and is able to swim swiftly under water. Yet it is otherwise very similar to our song-thrushes. Bats in the Mammoth Cave are able to fly, without ever brushing the walls, in the remote corners where the darkness is complete. Some fishes and squirrels and lizards and squids are fitted with membranes that enable them to glide, almost to fly, through the air.

Turn where you will, in any corner of the earth, to look at any animal, and you will always see some beautiful or astonishing contrivance for seizing a living in the fierce competition of nature. How are the bees able to save precious time and more precious wax by making cells with six sides rather than four? Or what steering device enables them to fly so straight that they have made a "bee line" a proverb? Maeterlinck's essay on the adaptations of the bee makes the *Arabian Nights* seem flat. The fire-fly's apparatus is the envy and despair of every lighting corporation.

We could continue to flit thus from case to case through all the vast range of the vegetable and animal kingdoms, and see in every specimen some new adaptation. From an elephant's trunk to the filament of a bacillus every detail of structure would furnish one more item for a record so extensive that no one person's life is long enough to read it. And even if we had time for examples from all parts of the tremendous catalogue, no such set of mere items would picture the principal truth. For when we look at one and another and the next each seems like

an independent exhibit, complete in itself, neatly stowed on its own quiet square foot of space in a dust-proof glass case. But in the swirling battle of life it is only a drop in the maelstrom, a part of the whole. No plant is adapted for itself alone; no animal is detached from the whirling struggle of the whole. Here are bacteria and flowers and ants that seem adapted for slavery to roots and bees and other ants. Elsewhere are poisons and claws that seem adapted only to destroy life. Everywhere in the maze there are plants like the mistletoe and animals like the tick that suck the food prepared by other plants and animals. These are the parasites. In one sense all the higher animals are parasites upon plants, for they could not live without the food that green plants can form from the air and ground. It is estimated that half of all the known species of animals are adapted to be parasites and cannot live in any other way. So adaptation is not all a matter of building up elaborate contrivances, but is often a case of giving up contrivances and becoming more simple and degraded.

Adaptation may not be a matter of forms. Often it is a set of impulses and instincts that direct animals to move to certain flowers or kinds of bark, or to take journeys of thousands of miles. Everyone knows that shad and salmon luxuriate for most of their lives in the ocean, and then are led by an irresistible impulse to run up rivers for spawning. The somewhat similar romance of the seals has furnished material to Kipling. We all know these commonplaces. A more striking example of adaptation is the opposite kind of migration made by the eels.[1] These peculiar fish emerge from

[1] The general nature of the life-history of the eel was correctly guessed at sixty years ago, and evidence of deep-sea spawning was gathered twenty years ago; the announcement of the discovery of the Bermuda spawning region was first made by the Press on July 22nd, 1922, in an account of Doctor Schmidt's seven-month expedition from the Copenhagen laboratory on the ship *Dana*.

the ocean to the English shore in their infancy as transparent, insignificant bits of ribbon two inches long; the females move up the streams and often journey overland; for years—sometimes ten or twenty—they continue to grow in size; then back they go to the salt water and swim south-west, swim for two years or even three, till they reach the deep water south of Bermuda; here they spawn; from here the young larvæ head north-east and toil back over the long, long weary three thousand miles, growing somewhat smaller during the migration; at length they reach the friendly fresh water where they can spend a happy decade, until they in turn are summoned to return to the cold depths, where they spawn and quickly die. These long journeys are an adaptation, and a very successful one; yet to our human way of thinking there is something cruel and creepy about it.

There is the same uncanniness about a whole host of migrations in nature. Certain fresh-water clams give birth to young that attach themselves to the gills of a particular kind of fish—not of other kinds—where they live as parasites till they are ready to drop off and grow up into clams. If our delicate tastes are offended by this life-history we may have one of the other sort—for there are all imaginable kinds in this jungle of adaptations. Read the pretty story of a fiercely-spiked yucca, the Spanish bayonet, whose stalk of beautiful blossoms is so much admired by tourists in the south-west part of the United States. This wealth of bloom would be impossible and the hardy plant would perish if it did not provide food for a certain delicate white moth—not any other moth—which brings it pollen from other yuccas. And the little moth could never live on the dreary plains if it was not fed by the sturdy yucca.

Such tales of ocean journeys and desert partnerships have a romantic quality that naturally excites us to

"think" about the origin of the adaptations. We had better follow the advice of the bird man and not exercise our feeble logic. It is safer just to notice the facts.

Observe the colours of animals. In many cases the splotches and irregular lines of a butterfly's wings are a minute imitation of the leaves on which a butterfly perches. A sharp-eyed collector has often had the experience of seeing a specimen suddenly disappear from sight as if by magic when it lights; so perfectly do its folded wings resemble the surrounding foliage. The marking of some insects is like the appearance of bark or stem; the stripes of tigers and zebras cause them to blend into the landscape, so that they can better stalk their prey or escape an enemy. All through the animal kingdom are instances of different sorts of camouflage that render an animal inconspicuous: bears and birds and hares are white in the northern snow, while most birds and lizards are green in tropical forests. Sometimes the most remarkable of these "protective colourings" are the least spectacular. Sometimes they seem poorly contrived. If a speckled, dull-coloured bird is protected by its markings, why should its breast be a shining white? An experiment showed why. An American artist painted two sets of dummy birds; to both he gave nature's colours on the back, and to one he gave nature's white breast; but to the other set he gave a dull-coloured breast. Then he placed his two sets of dummies at a distance and observed them. Those that were painted nature's way, with the light breast, blended better with the surroundings and were harder to see. Yet even the artist had not expected this result, and had a hard time to reason out the peculiar problems of light and shade.

It is needless, even if we had space, to continue zigzag journeys from snow to tropics in order to pile up the evidence that throughout the whole world of life many animals are adapted by their colours for the struggle to exist. Such a lengthening of the list would

be tiresome. But it will be worth while to notice two exceptions that prove the rule. (1) Some butterflies wear loud colours, seem to advertise themselves to hungry birds. This looks like the opposite of adaptation. But in such cases it will be found that the butterflies are protected in another way; they are for some reason extremely disagreeable to birds, which will not eat them. Hence they fly lazily about, for they are safer if they advertise themselves as an unpalatable kind. The wise birds know better than to catch them. (2) Some good-tasting butterflies are also conspicuous in their colouring, and also fly lazily about. Since they look nearly like the bad-tasting ones, and since they don't mind telling a lie about themselves, they are saved from the attacks of birds. And yet, for all their apparent resemblance, they belong to quite another family and are as different from the bad-tasting kind in structure and habits as pelicans are from eagles. What is more—incredible as the fact may seem—one species of good-tasting butterfly, within the limits of one country, has been found to imitate the appearance of three different kinds of bad-tasting ones.

At this point our uneasy powers of logic again throb for action, but the next set of facts shows the futility of logic. Among some species of good-tasting butterflies only the females are coloured like the bad-tasting species; the poor males have been left most cruelly unprotected. It is only certain species of these good-tasting butterflies that resemble the bad-tasting ones; other species are left without any imitative colouring. In one common genus only one species is disguised; all the others have to live without protection.

Descriptions of all the freakish ins and outs of insect mimicry would fill a big book. Some beetles resemble other beetles, while some resemble bees. Wing-covers are extended, antennæ knobbed, and legs made hairy in the most comical ways, so that the normal structure

can be detected only upon careful examination. A cricket has been found that—unlike all its relatives—has the outward appearance of an armoured beetle, and another cricket wears the garb of the very wasp that preys upon it. Shall we argue that nature first designed the wasp and then mocked it by designing a disguise for its prey? We have all seen fierce-looking flies that masquerade as hornets and that have a body motion like a hornet. Is nature favouring these flies with her contrivance, or is she cruel to all the other flies? Some flies resemble bees and daringly invade hives to lay eggs; the larvæ that hatch from these will eat up the young bees. Why should nature design such a crafty deceit of the bees, or why should she leave the poor things so witless as not to recognise the murderers? We could "think" that she played the same scurvy trick on some ants in Brazil, reasoning that when she made a little mantis in exact imitation of them and sent him among them to kill them she was determined to punish them for wearing the clothes she had given them.

We have had enough examples of how sensible the advice of the bird man was. If more proof were needed, we could reprint pages of Wallace's chapter on Mimicry in his *Natural Selection*, telling how a caterpillar resembles a snake in colour and pose—and many such oddities.

Adaptation is a bigger and more fascinating subject than any mere list of curiosities. It includes all those marvels of architecture that can be seen in whole groups of animals. We had best not describe the most astonishing of these, for they might give an impression of exaggeration.

We may pass by such wonders as those of blood and digestion, which are largely beyond our ken, and speak of some bit of mere anatomy.

Look at a feather. We can see it is adapted for propelling a bird through the air in search of a living. Have you ever examined a feather or thought anything about it? Man has not made any material so light and

stout and elastic as the thin, horny quill. We say familiarly "as light as a feather," but we might better say "such a miracle as a feather." For its make-up is admirable beyond all description. From each side of the central shaft branch hundreds of miniature feathers, the barbs, each of which sends out its hundreds of branches, the barbules. These are airy plates, each of which is delicately and accurately frayed into hooks on the forward edge, delicately and accurately grooved on the rear edge. Each barbule fits its hook neatly and firmly into the barbule in front of it and holds in its grooves the hooks of the barbule behind it. So precisely are these couplings made that the surface of a wing is as smooth as paper. One student of birds counted the parts of a crane's feather; there were over one thousand three hundred barbs on one side, each of which branched into six hundred barbules —eight hundred thousand adaptations on one side of "just a feather." And then the wonder has only begun. The different feathers on a bird are not all duplicates of one pattern; there are all lengths, all degrees of fineness from plume to down; there is a whole range of uses— for flight, for water-proofing, for warmth. When we have counted the parts of one feather and multiplied by the number of thousands of feathers on some heron that wades for minnows in a remote lake we begin to get a glimpse of what adaptation means in nature.

We often speak of these adjustments as "perfect." So they may seem. If we examined the sole of a fly's foot, noting the suckers and hairs that enable it to run about on a smooth ceiling, we are excusable for exclaiming, "A perfect contrivance!" But there are many exquisite structures at which we can only guess. We can, for example, see the remains of a certain microscopic plant which goes on propagating in trillions age after age and dropping its tiny shells to the bottom of the lake in which it lives; we can see that the markings on these shells—125,000 to the inch—are exactly equal and spaced

at exactly equal distances from one another; they are so infinitesimally precise that they prove man's most skilfully-made lenses to be clumsily inaccurate. Such perfection of structure could not have been an accident; yet we do not know the use of it. We can only look with awe at these products of an unseen force of adaptation.

There are some features of plants which appear to serve no purpose whatever. In other cases—as when potatoes grow on stalks in the air—the machinery of the plant seems out of order. In many ways a long familiarity with plants causes a botanist to feel that adaptation is a means of "doing well enough" or is "a chance product of the play of forces"—and so is far from perfect.

An adaptation is often successful only for a time, in certain peculiar conditions. For instance, if a naturalist could have studied animals some millions of years ago he might have called a "Thunder Lizard" perfect for its surroundings, because the bones a foot thick were such superb engineering for a cantilever skeleton that was sixty feet long. But when the climate changed the Thunderer proved very, very imperfect, and his race died out. The record of the fossils is one long roll of creatures that were "admirable" and "perfect" adaptations for one way of life, but that perished because they were unable to live in competition with better forms. No doubt the old sabre-tooth tiger was king of the beasts by virtue of the formidable weapons in his upper jaws, and no doubt the Irish elk was justly proud of his hundred-pound antlers, the hugest the world ever saw; but both adaptations were good for only one set of conditions; when the conditions changed the adaptations brought their owners to destruction.

Many and many an adjustment that we see about us now is only partly successful. It appears that the bee is just well enough adapted to thrive, and no more: her instinct drives her to toil with such incessant vim

that she dies after a few days of work at the height of the season; in many ways she is stupid. The teeth of a beaver are certainly a successful adaptation in one way, but if they are not kept worn down by constant gnawing they grow so long that they kill the beaver; that hardly seems a perfect arrangement. Flies are a good example of successful adaptation, yet they are so imperfect that they are subject to the ravages of a plague of fungus. Silkworms and elm trees have been threatened with extinction. We may properly speak of an eye as a most marvellous adjustment, may call it perfect, but in reality it is far below what an ideal instrument might be; one great student of optics has said that it is so inexact and imperfect that we might almost suppose nature was trying to keep us from knowing what the world really looks like. The way in which the leaves of plants can adjust their "breathing" to changes of temperature and moisture is a notable case of adaptation; yet it is so far from perfect that when a leaf opens its pores to let gases in and out it may allow too much water to escape, and thus sometimes commits suicide. Adaptations are known to be imperfect, to suceed one time and fail another.

The botanist, as he studies the ways in which flowers are adjusted for bees, cannot escape the feeling that all these beautiful and intricate devices are temporary, that flowers and bees have not always had this curious partnership. And the geologist says, "You are right. Only a little while ago, geologically speaking, there were no bees and no bright flowers in the world." So the botanist finds a double fascination in his study of the ways in which flowers are decked in colours and perfumed, their sweetmeats displayed, their barriers and passageways rigged up, their stamens and pistils set in order—always in such a manner that some bee or moth or humming-bird is tricked into carrying pollen. Every coloured flower is a fit subject for a long essay on

adaptation: it must have pollen from some distant blossom, and must have its own pollen carried to another blossom; this conveying is done for some plants by the wind—and these have no colours or sweets; but plants which depend on insects lure them and pay them. Here is Darwin's description of how one orchid operates:

"This orchid has part of its lower lip hollowed out into a great bucket, into which drops of almost pure water continually fall from two secreting horns which stand above it; and when the bucket is half full the water overflows by a spout on one side. The basal part of the lip stands over the bucket, and is itself hollowed out into a sort of chamber with two side entrances; within this chamber there are curious fleshy ridges. The most ingenious man, if he had not witnessed what takes place, could never have imagined what purposes all these parts serve. But Dr. Crüger saw crowds of large humble-bees visiting the gigantic flowers of this orchid, not in order to suck nectar, but to gnaw off the ridges within the chamber above the bucket; in doing this they frequently pushed each other into the bucket, and their wings being thus wetted, they could not fly away, but were compelled to crawl out through the passage formed by the spout or overflow. Dr. Crüger saw a 'continual procession' of bees thus crawling out of their involuntary bath. The passage is narrow, and is roofed over by the column, so that a bee, in forcing its way out, first rubs its back against the viscid stigma and then against the viscid glands of the pollen-masses. The pollen-masses are thus glued to the back of the bee which first happens to crawl out through the passage of a lately expanded flower and are thus carried away. When the bee, thus provided, flies to another flower, or to the same flower a second time, and is pushed by its comrades into the bucket, and then crawls out by the passage, the pollen-mass necessarily comes first

into contact with the viscid stigma, and adheres to it, and the flower is fertilised."

From a picture of that sort we should like to go on through the gallery of adaptations, seeing how one plant spreads all its flowers and leaves in a space no larger than a pinhead; how leaves and roots, when they first emerge from the seed, do not grow in the wrong direction; how plants blossom late or early, and thus avoid some competition; how the tips of roots are highly organised mechanisms for pushing through stiff soil and forcing water, with substances in solution, up to the stem; how burs hook themselves to cattle by the most delicate barbs, and milkweed pods send out their seeds in the finest silky parachute; how sap is pumped up three hundred feet in tree-trunks by a process that no physicist has yet explained. But there is not space in this volume to do more than hint at the endless variety of ways in which plants are adjusted to live.

A set of pictures of ingenious mechanisms is all very well for entertainment, but is apt to blind us to the far more marvellous facts of adaptation that are to be seen in the anatomy of any plant. If we, like a child, are satisfied with shouting, "Oh, see the pretty seed sail!" we shall forget the deeper wonders of the structure of one of those gossamer threads that float the seed along. Every slightest shred of such material passes understanding.

Here at our feet is a bunch of clover. As you look at it indifferently you are, in comparsion, like some giant a million miles tall who is looking at our earth. If his eyes were no sharper than ours he could not detect London or the height of the Alps. So, if we wish to see anything of a clover leaf we must make ourselves small. We must reduce ourselves to the dimensions of a medium-sized microbe—to the height, say, of one ten-thousandth of an inch, while we retain the vision and the mental

powers of a man.[1] Permit yourself to be thus minimised while we take an excursion for a few paragraphs into this clover leaf that nods in the breeze—just an ordinary, matter-of-fact, humdrum leaf that is carrying on its existence by the use of certain commonplace adjustments to soil and light. Shrink yourself gradually, and thus avoid too great a shock. First you are two inches in height—four times as tall as the width of the leaf, which now looms before you a spiny, big-ribbed affair, glowing with life. Then you are reduced to a tenth of an inch; you cling to the edge of the leaf, which seems thirty feet broad, and you feel a vertigo as a breath of air swings you through an arc of twenty feet. Become ten times smaller still; the leaf is a hundred yards broad, and the little fuzzy hairs appear as spiny trees fifteen feet high that glisten against the background of billowy green. If you submit to another similar reduction, the opposite edge of the leaf will be more than half a mile away, lost to view beyond the swell of the surface. One last reduction, and here we are—two microbic pygmies at the edge of a leaf nearly six miles wide. We find ourselves perched on a ridge that is as rugged and jagged as an arm of a volcanic mountain. Indeed we are on a more perilous footing than the climbers of Skiddaw, who walk across a ridge that slopes steeply down two thousand feet on either side; for our leaf is in its fleshiest part less than a thousand feet thick.

Beneath us we feel the throb of the mighty protoplasmic engines; we have glimpses of great streams coursing beneath the shining water-proof surface of

[1] I have tried to carry out Ganong's hints: "The student can see photosynthesis proceeding as clearly in imagination as he could with the physical eye were he sufficiently small to wander at will through the intercellular passages, and view the operations through the crystalline walls of the cells"; and "the ordinary stoma [pore], when open, presents to a molecule of water an exit as great as a passage seven miles wide appears to a man."

the top, which undulates for two and a half miles to the chasm that is over the midrib. All this plateau is covered by a forest of the white spines that rise like giant masts of crystal fifteen hundred feet above the network of blackish veins.

Before we venture into the terrifying interior of this monstrous place, be assured that we are not playing with a fantasia. Small as we have made ourselves, we are not nearly small enough to penetrate the last secrets of a leaf. Our vision is still far too coarse to see even the most puffed-out molecule of starch or sugar, which would be to our gross microbic eyes only one two-hundred-fiftieth of an inch in diamater. No, small as we are, we have descended only to those limits that a microscope can reach, and are still like great blinking monsters before the ultimate adaptations.

We are altogether too large to enter through the upper side of the leaf; no space there would admit a finger. We peer along the under side. About a hundred yards away is a hole that looks promising. Fortunately there is a thousand-foot spine, rooted beyond the opening and growing across it, close along the under surface, that offers us a rough bridge. We scramble along on this huge, sparkling log, below the under surface of the leaf, till we are beneath the mouth of a cave. At first we are almost blown off by a blast of oxygen that is rushing out, and then are almost sucked in by a whirling current of air. At the edge of these currents we find a place where we may swing ourselves by our hands up to an oval aperture that is heaving in an alarming manner. We can feel the surge of sap in the bulging guard-cells, which sway the wall of the cavernous mouth to and fro; they might quickly swell scross the opening and crush us. Luckily at just this moment they are slowly drawing apart.

We venture between them when the opening becomes five feet wide. We find ourselves at the bottom of a

funnel whose wall rises steep and slippery forty feet above us. Up this we clamber. Here at last is quiet and security, for we are in an open space some fifty feet wide and a hundred high, whose sides are composed of a dozen or more irregular blocks. Imagine some houses, with elastic walls, wedged tightly but not accurately together to enclose a great chamber, and you will have an idea of the surroundings that close us in. The walls of these houses are six inches thick, but so nearly transparent that we can make out fairly well what lies behind them—green globes and discs, ten feet or more in diameter, that are suspended in a sort of thin syrup, and that are slightly in motion. The "houses" are the cells. The green globes are the machines that manufacture sugar—and sugar-making is the chief business of a leaf. In the course of a summer it will produce enough sweet food to form a layer half a mile deep over its whole surface.

If we wish to explore, the way lies open above. We had best take our bearings, so that we shall not get lost in the galleries that ramify among the big cells. Our forty-foot climb up into this chamber was through the under surface of the leaf; we are now in its soft interior. Above us lies the thickness of the leaf—perhaps six hundred feet—which is packed nearly full of the house-like blocks, through whose walls we have been looking. These are the green cells; half a dozen layers of them are between us and the top surface of the leaf; all around us they stretch, out to the very edges—a million or more of them. We are going to climb around through the air passages that twist and wind in every direction among the cells, and we must keep good track of our directions, or we shall never find our way back.

Through the air-passages we poke our way between the pulsing walls of the cells and mount towards the upper side of the leaf. The cells become more narrow, more close-packed, more green, until, when we have struggled

upward four hundred feet, we come to the base of a close array of them that are much longer, wedged tight together, like so many flexible packing-cases, reaching to the upper surface. They deserve their name of the "palisade" cells. At one point we can squeeze another hundred feet through an air-channel, but here it ends, and we must stop.

Familiarity with these more active upper cells shows somewhat of their inside. The sugar-making discs, smaller and flatter here, float in a liquid. But the liquid is only the lining of the cell. All the interior is filled tight with sap, which holds the syrup against the wall.

We never tire of watching this syrup, viewing it as if through the glass of an aquarium. It is in constant motion, sometimes swirling by a mile[1] a minute, sometimes busied with little whirlpools; now it is of the faintest green colour, and now yellowish; here it is a thin, translucent jelly, and there is filled with fibres and rods, globes and crystals. It is protoplasm. It is life. Whatever other wonders we see in a leaf are explainable to some degree by a chemist, but man has hardly spoken the first syllable that shall help to interpret protoplasm. When we have begun to understand it we shall have begun to understand life—not before. It is as different from mere sugar as a man is from a stone. If you grant a biologist just one cell full of this protoplasm, he can imagine that from it came all the classes of life; without it he cannot account for the beginning of life; all inorganic matter, be it ever so complex, is on one side of a great gulf, and protoplasm is on the other side.

What a purblind, witless thing is man when he encounters a leaf!

[1] Actually four miles—if a mile is reckoned as nine hundred times our microbic height.

As we continue to explore we are overpowered with the complexities that surround us, of which we can gain hardly any knowledge. Here is a strange cell that contains, as if it were a show-case in a museum, a glittering, spiked crystal five feet in diameter. We are bewildered by the currents all about us: air circulating everywhere, water pumped through tubes, sugar carried out for transportation to the roots that need the food, sugar transformed to starch and back again to sugar.

And all these operations are simple compared with the other functions of a leaf. Not all of man's laboratories can equal the refinement of the varied processes that go on every minute here. There are special cells to produce the water-proofing for the outside of the top; others make cellulose and build the walls of veins with it; there are the guard cells that regulate the intake and outgo at the pores. A leaf compounds the most delicately adjusted kinds of intricate carbohydrates and proteins, of oils and fats and colouring-matters and alkaloids and digestive fluids and acids, and many products that are quite beyond detection.

Suppose that the human mind could partly grasp the possibility of assembling all these activities in a soft plate half an inch wide and one-hundredth of an inch thick; the mind would only have begun its journey of understanding. What regulates and directs the whole organisation? Where is the "nerve centre" that tells ten thousand pores to open five per cent. wider because the temperature has changed? Where is the mechanism that controls the turning of leaves for a better spread to the sun? Whence issue all the uncountable thousands of orders every hour to the hundreds of thousands of cells, telling them when to work and when to desist? What engineer so directs the currents that in every least vein the sugar is floated toward the stem and water is propelled in the opposite direction? We weary of a mere rehearsal of a mere part of these orders for work.

Our excursion is over. Now we may enlarge ourselves to our normal size and be again the blind and massive monsters who can see nothing in a leaf. We look down at the hall of wonders where we spent such an adventurous hour—at a mere clover leaf bobbing in the wind. Somehow our minds are no longer interested in "thinking" about adaptations. For all this assemblage of intricate powers is but a fragment at the outer edge of a tenfold more marvellous assemblage—a whole plant, whose leaves and roots work as one body for producing flowers that can summon the bees to aid them in producing seeds. And a seed is the supernal wonder, for within its narrow case are enclosed all the adaptations of a mature plant, every detail of every kind of roots and sap-ducts and stems and sweet scent and future seeds. Here within a seed is a universe which appals the mind as much as the farthest reach of the starry spaces, and which is farther from our comprehension. Here centres the whole of life. All adaptations are but means to this end—that the power to live shall be passed from an individual to its offspring. If we would know the little that the scientists can learn about the secret, we must lay aside all our gross and savage superstitions as to how nature might work if she were a mortal. We must realise that nature is not revolving around our human ways of thought to be a convenient servant to us, but that her secret is the remote force about which our petty minds swing in their unknown void.

Probably we can never grasp the secret, any more than an astronomer expects ever to fly to the sun. But we can observe it to some extent. We can see a little way into the material facts of life, and can learn how great is the distance from the heedless disregard of a leaf to the central fact of adaptation.

CHAPTER VI

THE STRUGGLE FOR EXISTENCE

THIS chapter is the first of four steps in describing evolution. It is a description of the fundamental fact —never understood a century ago—that the life of every plant and animal is a struggle in a fierce competition for a chance to exist and propagate. If nature had caused all her creatures to live by a policy of "give the weak ones a chance" there never would have been any development of such adaptations as were described in the previous chapter.

Early in every man's life there comes a time when he hears the story of the blacksmith who offered to shoe a farmer's horse for some grains of wheat—thus: one grain for the first nail, two for the second, four for the third, and so on. Of course, the farmer was pleased with such a price. The driving of the fifth nail cost him only sixteen grains, and the total wages for putting on the first shoe were only two hundred and fifty-five grains. The farmer kept tally: two hundred and fifty-six grains for the ninth nail, five hundred and twelve for the tenth, one thousand and twenty-four for the eleventh. He was amused, and the more so because his wheat was small; it took five hundred of the grains to fill a cubic inch, and a million of them to make a bushel. The last nail of the second shoe cost him not much over a quart. He lighted his pipe and smoked contentedly, reflecting that he was paying hardly anything for the labour and nothing for the material.

The trouble began while the third shoe was going

on; the twentieth nail cost 524,288 grains—half a bushel; the twenty-first a bushel, the twenty-second two bushels, the twenty-third more than four bushels; the total for the third shoe amounted to sixteen bushels. The thirty-first nail cost over a thousand bushels; the total price for the job was four thousand two hundred and fifty-six bushels.

When we tell this story to children we are amused at their scepticism and pleased with our effort to show them the difference between adding two and multiplying by two. We do not realise that we need the lesson for ourselves when we consider successive generations of animals. The rate of increase is not found by *adding* to their number each time, but by multiplying. Most animals tend to increase by a factor larger than two, and it does not require a long stretch of years to include thirty-two generations. Even a seasoned mathematician is rather startled when he reckons the numbers of descendants that one pair may produce in no long while.

The largest and most slow-breeding kind can furnish amazement if we grant them a few centuries. Suppose that the average pair of elephants produces only four children that live to have grandchildren, and suppose that there are only three generations in each century, and suppose that the parents die as soon as they have brought up their last child. Under these conditions one pair will have sixteen great-grandchildren in the world after a century, one hundred and twenty-eight descendants after two centuries, and one thousand and twenty-four after three centuries. The rate of increase may seem as insignificant as it did to the guileless farmer. But in five hundred years there will be sixty-six thousand descendants, in six hundred years there will be over half a million, and after another century over four million. Now the numbers roll up. In the thirty-second generation of descendants there will be 8,500,000,000—that is, five times the human population of the globe. After seven

more centuries of increase there would not be standing room for the elephants if they were packed closely on every acre of land surface from pole to pole. Does seventeen centuries seem a long while? It is not the thousandth part of the centuries during which elephants have been breeding on our earth.

There is no trick in this reckoning; the figures do not lie; they give a conservative estimate of the way elephants actually would have increased if they had had a chance. We know as a matter of history that a few horses left by the Spanish conquerors of Mexico to run wild must have increased on the American plains for a century or more at a rate that doubled their numbers in each generation.

As soon as we deal with smaller and more short-lived animals the normal rate of increase is prodigious. In 1860 a few rabbits were carefully conveyed to Australia and tenderly nourished there with the hope that a few of them might be able to live and propagate. Never was a hope more abundantly fulfilled. So rapidly did they multiply that within twenty years they were a pest; rabbit-drives had to be organised, and such heaps of the animals were slaughtered that it was difficult to dispose of the carcasses. A fence of wire mesh was run clear across the continent in order to check this avalanche of life.

Any animal that bears several young in one litter and breeds several times a year can soon make a counting-machine weary. In two years of the World War the rats multiplied enormously along the battle line—amid all the destruction of artillery and poison gas, in spite of the utmost efforts to hold them in check. Against the unremitting warfare of man, rats have always increased wherever there is food. One estimate of their fecundity in England is that, even if ninety-five per cent. of them died without breeding, they could quadruple their numbers in a year. If they had food and room, and were not

opposed, their skins could make a carpet for the earth in a few decades.

Some similar computation would be true of any animal that is normally adapted to hold its own in the world. It is fitted to increase in swarms, and ever multiplying swarms; and whenever it has opportunity, it infallibly lives up to the predictions about its fertility, actually does propagate in overwhelming numbers. The English sparrow was taken to America in 1851, and promptly set to work producing every season several large broods. Within twenty years it had become more numerous than any native bird. The point of this story is not that a certain sparrow became an undesirable citizen, but that any bird in a favourable environment will unfailingly produce astounding numbers in a few years. A very moderate estimate will show that a pair of blackbirds could easily become ten millions in ten years, and that many ordinary birds could have two thousand millions of descendants in fifteen years — would unquestionably have that many in favourable surroundings. When the Ohio Valley was being settled the pigeons used to be seen in such numbers that we gasp as we read the naturalist Wilson's account of what he once saw in Kentucky: "They were flying with great steadiness and rapidity, at a height beyond gunshot, in several deep strata. From right to left as far as the eye could reach, the breadth of this vast procession extended, seeming everywhere equally crowded. It was then half-past one. About four o'clock in the afternoon the living torrent above my head seemed as numerous and extensive as ever." Wilson reckoned that in this one "torrent" there were two thousand million pigeons; and this was "only one of several aggregates known to exist in various parts of the United States." Yet these pigeons hatched *only two eggs at a time.*

Every form of plant or animal life has some similar ability to multiply its numbers. Until we hear that

statement repeated, and repeatedly emphasised with examples, we cannot have any conception of the prolific power of all life. For even observant people have very little opportunity to realise the abounding vitality of all animate nature. And most of us are not observant. I, for example, hardly see one rat a year, hardly know an English sparrow by sight, am much impressed by the way my trees and shrubs tend to die. I always see, year after year, the same numbers of rooks or pheasants or hares. What do I know about the power of life to multiply?

No one can realise that power who has not seen an example of the swarming of animals. On the American plains the sky has sometimes been darkened at midday by the locusts that were preparing to descend on the fields of maize. They come, as they come in Africa, from some distant breeding-grounds in hordes so vast and destructive and swift that they stagger the imagination. About the middle of the last century a sudden pest of caterpillars appeared in the forests of Prussia; so numerous were they that the noise of their droppings was like the rustle of rain.

The history of the potato-beetles in America is more extraordinary than the tale of Tartar tribes. For unnumbered centuries they had lived a hard, obscure life in the Rocky Mountains, feeding meagrely on a plant that belongs to the genus of tobacco and potato. About 1850 one of them sniffed something delicious in the breeze. She flew in that direction and lighted on a cultivated potato plant that was in a settler's garden. The power of fertility increased with this new food supply, and across the fields of the juicy, helpless leaves it took its devastating course. Within a few years the potato-beetles became an advancing army; they spread north and south, deploying on the plains with a front one thousand five hundred miles wide and rolling eastward at an average speed of two miles a day during the two months of summer

when they could breed. If there had been food, and no enemy to spray with poisons, these beetles would by this time have been numerous enough to pave the earth with a layer of their wing-covers.

There is nothing exceptional about such increase of numbers. It is an entirely normal case, one that would be duplicated in a few decades or centuries by any ordinary animal that found favouring conditions. It has been surpassed by the more recent increase of the cotton-boll weevil. The head of the American Entomological Bureau has declared: "The Mexican Cotton-Boll Weevil has the unique record of developing in less than twenty years from a most obscure species to one of the most important economically in the world." He estimates that during the five years after 1917 it destroyed property of a value of more than a thousand million pounds. He has not set any staff of clerks to estimating the rate of multiplication of the little beetle. He has been too busy trying to fight down the increase of another boll weevil, a pink one from India, that had the best of a four-year battle with the forces of the Bureau and multiplied enormously against all odds. In June, 1922, the Press reports stated: "State commissioners of agriculture estimate that the boll weevils are about five times as numerous as they have been before at this period of the season."

Every book on evolution gives illustrations of the way each species is fitted to multiply boundlessly. One of them [1] says: "If every egg of the herring should develop to an adult fish, it would not be long before the Atlantic Ocean would fail to contain them." Another [2] cites the case of a species of white ants: "A female, after it is full-grown, does nothing but lie in a cell and lay eggs, producing eighty thousand eggs a day steadily for several

[1] W. B. Scott, *The Theory of Evolution*.

[2] Jordan and Kellogg, *Evolution and Animal Life*.

months." A third[1] contributes estimates of this sort: "A single fern-leaf of a common species produces about fourteen million spores; a tape-worm produces hardly less than one hundred million eggs."

It will be safe to repeat the statement that these cases are not exceptional; they represent the normal provision of many plants and animals for propagating themselves. They are so commonplace that every author may set forth fresh ones. We must not lengthen out our list unduly, but should indicate briefly the inconceivable fecundity of several other classes of life to whose existence we seldom give a thought. When I try to find earth-worms for bait, I seem to prove that they are a very restricted genus; but it has been shown that in rich soil there is an average of fifty thousand of them to the acre. There they work, unknown to me, patiently grinding up stomachfuls of leaves and dirt for a little nourishment, and then casting out the residue. "In many parts of England," Darwin tells us, "a weight of more than ten tons of dry earth annually passes through their bodies, and is brought to the surface in their castings, *on each acre of land.*" Huxley reminds us that in the body of a living fly there may be "countless millions" of individual fungus plants. When passengers on an ocean steamer see night after night the phosphorescence of the water, every sparklet of light in the steamers' wake for thousands of miles is made by an individual animalcule. In all parts of the tropical oceans are little coral animals that fasten themselves to rocks, like sea-anemones, and there make for themselves a limy skeleton which remains after their death; so tremendous is their power of reproduction that they have built the Great Barrier Reef of Australia, one thousand two hundred miles long and in many places one thousand eight hundred feet thick. In stagnant warm water we find animalcules whose grotesque forms can be seen

[1] Weismann, *The Evolution Theory.*

readily under a small magnifying-glass. One species has been found to breed at the rate of six hundred generations a year. It has been estimated that if every individual should breed in normal numbers for five years and if none died, the volume of the three thousand generations would be "approximately equal to 10^{1000} times the volume of the earth."[1] Remind yourself that 10^{1000} means ten with nine hundred and ninety-nine ciphers after it, and that such a sphere would include more space than astronomers have measured.

It is easy enough to see why the animalcule does not continue its rate of increase — there is not space for it in the universe. It is clear why no fish has packed the ocean full and why elephants are not standing five hundred thick on every acre of land. The reproduction of every species—even if it were the only one in the world —is limited by the supply of food. And since there are half a million species of animals, each of which would like to fill the earth and would be quite able to do so, there must be a severe pressure upon every species by all the other species that are tending to swell in numbers and to occupy the same territory. Such a pressure must cause intense rivalry; it must restrict, must strongly check, the increase of each individual. This check upon the increase of numbers causes the "Struggle for Existence."

As soon as we hear that ominous phrase, we naturally begin to think of warfare, of bloody design. Indeed the literature of evolution is dotted with hints of this sort, and of late years the story-writers have given us many pictures of the world of nature as a battle-ground where all feet are swift to shed blood, a cruel place where venom and claw make way with enemies, where "nature is red of tooth and fang," where life is a "gruesome cockpit." This horrible notion is so generally held that it has been used to justify human warfare. The German Bernhardi

[1] L. L. Woodruff's *Foundations of Biology*, p. 375.

actually argued as crudely as this: "Wherever we look in nature, we find that war is a fundamental law of evolution. This great verity, which has been recognised in past ages, has been convincingly demonstrated in modern times by Charles Darwin."

In the main all such ideas are false. To compare the struggle of nature with human warfare is absurd. Because we human beings are cruel to one another, because *we* plunge into ruthless wholesale killing, because *we* have tortured and enslaved and exterminated one another in our struggles for *domination*, we cannot assume that the struggle for existence is similar. Only a gorilla has a right to such an argument. Before anyone can have a true view of evolution he must thoroughly purge his mind of this common and deep-seated error. Before we go on in this chapter to picture the struggle for existence as it is we must take time to see what is not.

It is not what our sentimental human minds would suppose. If we conceive it as cruel, as fierce-minded, as warlike, we are making the old mistake of having the great sun of nature revolve around our little mental sphere. Nature is not bitter with human hate. Nor, on the other hand, is nature sweet with human sentimentality. Nature is as different from a man as the starry heavens are from their reflection in a pool. "Nature" is simply a name for The Way Things Are. In this great scheme of things we cannot detect any plotting of altruism nor any exercise of cruelty, neither sympathy nor jealousy. To our poor senses nature may seem like a loving mother, or like a stern, inexorable stepmother; but the beauty and the harshness alike are flimsy maginings; they are not nature.

The struggle for existence does not invite men to go to war nor certify that might makes right nor discourage charity. It is not hideous, but partakes of the beauty of all truth. It contains no cruelty, unless all facts are cruel.

In the whole long history of false reasoning there is no funnier chapter than the record of how man has sentimentalised the struggle for existence. He has shuddered at the fierceness of the tiger while digesting the beefsteak of a slaughtered cow. He has written poetry about "the pious robin"; yet for every kill of a tiger a robin will slay his hundreds. The only relentless and unreasonable slaughterer on earth is man. No wonder that man, who exterminates moose and bison while he tolerates the marriage of idiots, is quite unable to comprehend the wisdom and purity of the struggle for existence that is decreed by nature.

The struggle for existence is a contest in which there is no motive of cruelty, no lust for power over others, no desire to do harm to another creature. It is an effort by every creature to do his best, his utmost, to live and have young. Every force of his being is animated by these two elemental instincts: (1) he must live according to the law that nature has planted in him, and (2) he must obey the primal commandment to be fruitful. Every act in the natural struggle for existence is entirely innocent and wholesome.

In another way the struggle is unlike what we might assume. It is not a universal combat in which every creature's weapons are turned against other creatures. In a great variety of ways animals and plants are useful to each other, confer benefits on others in the course of seeking their own welfare—as when birds remove caterpillars from leaves. Success in the struggle often comes from avoiding competition—as when the sage-brush grows on the desert where other plants cannot live.

In another and more important way the struggle differs from what we have so far dwelt on. It is to a large extent not a set of duels between individuals; the contest is often impersonal, unfelt, unsuspected. Perhaps an illustration from human life will be useful here: if an actor or an author pleases the public his

work may be highly paid for, and the income of some other actors or authors be reduced. Stevenson says that a successful author—who may be a shrinking, affectionate person—stabs other authors with his pen as surely as if he used a dagger. So impersonal and unsuspected may the struggle for existence be at times in human affairs. Much more is it true that the unreasoning lives of a large part of the animal kingdom may be passed without any consciousness of rivalry, in peaceful success. Success need not depend on the ability to kill. All through the millions of years of the geologic ages the armoured fighters have perished; to-day one of the most prolific animals is the least offensive—the hare. The rats and beetles have not conquered in the strife by slaughter. Some of the most successful animals are those that organise a society, like the ants and bees, in whose colonies there is no individualism, but only a ceaseless, unstinted labour for the whole group.

But the struggle, for all kinds alike, is none the less fierce and unremitting because it is indirect and unknown. It is pitiless. If a communistic society of bees cannot find nectar in competition with other societies, it will fail to leave offspring as surely as the lonely pair of eagles that fail to strike enough victims in their wide domain of sixty square miles. When any kind of organism cannot produce enough seed, or suck enough water from the ground, or resist a plague of fungus, or withstand a change of climate, it dies. There is no more tragedy about this for the individual than there is about the most successful life, for every individual, weak or strong, must die. The only difference is that, in the long run, the weak leave few offspring; the earth is peopled by those who leave most offspring. "Reproduce or perish" is the eternal necessity. In this struggle to propagate the mushroom feeds upon decaying matter, the condor wheels its lonely flight above the mountains, the fish feels its sightless way in caves and ocean depths, the mosquito

swarms beyond the arctic circle, the snow-plant spreads its abundant red upon the ice-fields of cold heights, the beaver builds his dam. High and low, everywhere under the whole heaven, in every cranny of space, with every imaginable adaptation, the urge of life compels every individual to seek out a living and have young.

Though we can learn very little about the adjustments in nature, we can guess them to some extent by what we see when man disturbs any balance. As soon as the dry valleys of California were set to orchards about fifty years ago the cottony cushion scale multiplied upon them at such a rate that destruction was in sight. The orchards were rescued by studying nature's adjustments in Australia, the home of the scale. It was found that there the scale was kept in bounds by ladybird beetles ; some of these were imported, bred and turned into the orchards ; they promptly and completely played their expected part in the struggle for orchards. The cantaloupes were saved from a pest by a similar army of ladybirds brought by the bushel from the high Sierras. Man's best, and often the only, way of coping with the multitudes of nature is to employ the troops of nature, as in fighting the gipsy moth, the Hessian fly and the grain aphis. We are in a perpetual contest with the hordes of life that swarm against our interests.

Some such gross examples are about all that man can learn of the interplay of forces that work in the struggle for existence. If we look at any landscape, we see that all forms of life are fitted into a mosaic where each can thrive to a certain extent, thus far and no farther. Each is, in the ordinary course of the seasons, checked from dominating over others. Grass and spruce trees and violets and robins exist in abundance, and now one and now another may fluctuate somewhat in its numbers ; but as the decades pass the balance only swings to and fro about a centre. Each plant and animal is severely restrained by the whole competition. Year after year we

look upon the same peaceful assemblage, hear the same songs, see the same bright blossoms, exclaim with the same satisfaction at the restful peace of it all.

But there is no peace. In any landscape each leaf and beak and fin is tirelessly at work to keep up its numbers. Every plant bears seeds in prodigious quantity; every animal's body is a factory of countless eggs or sperms. With all the power of every mother's being there is effort to rear young. Every pair of individuals is doing its best to leave descendants that would spread over the whole region. With what result? Only this: that next year, and ten years hence, and fifty, and a hundred, there will probably be the same number of descendants. All this ceaseless power is somehow held in check by the competition of powers. Of all the seeds that are formed by a plant with such lavish extravagance only a few sprout. "There is a British starfish which produces at least two hundred millions of eggs, *and yet it is not what one would call a common animal*."[1] There is something fearsome about such tremendous possibilities that accomplish no more than just to keep the numbers of this starfish from decreasing. Many of the lower animals hatch a thousand eggs to ensure one offspring. And only a small fraction of the young can grow up. The rearing of all the offspring with such intense devotion has only one result, that when the years have passed and the parents have died there are two other members of the species to take their places.

Here is a fact to which the ordinary citizen never gives a thought. The pretty scene that he surveys while taking a walk is a cemetery for the young that never mature. We need not weep for their fate, but we observe the fact. This is the struggle for existence.

[1] J. A. Thomson, *The System of Animate Nature*.

CHAPTER VII

VARIATION

THE previous chapters have been descriptions of life as a naturalist sees it—bird's-eye views of what plants and animals are like. In this chapter and the next two we shall spend some of the time studying the inside of eggs.[1] At a point where the course changes in this way we had better look back a minute to see what ground we have covered.

The first four chapters, displaying the myriad forms and the tangled web of life, were a preparation for Adaptations. Until we realise something of the intricacies of life, we cannot see much of a mystery about their adjustments. When we have had a good look at Adaptations and have wondered how they were made, we are ready for the explanation. The explanation is in four steps: The Struggle for Existence, Variation, Heredity, Natural Selection. The first of these (in Chapter VI.) was a view of the way every form of life is doing its best to multiply, though it can seldom do more than hold its numbers even. Looking at this struggle was a survey of the facts as a naturalist sees them.

But Variation is different. Here we quit tramping

[1] A biologist uses "egg" to mean the female germ of either an animal or a plant. After the fertilised egg of a plant has reached a certain stage of its development as an embryo the development ceases; and this dormant embryo is what we know as a seed. It would be convenient, and perhaps not misleading, to speak of eggs and seeds as synonymous terms in this elementary book, but a biologist could not tolerate such a use of words. "Egg" in this chapter means any fertilised germ-cell of any plant or animal.

in the open with Darwin and Wallace; we are in the laboratory, looking through the microscope at revelations that have been made since Darwin died.

Variation,[1] as used in this chapter, means simply the fact that young are never precisely like their parents. We know that no child ever exactly resembled its father and that no tree was ever an accurate reproduction of its mother. We do not need to be told that among all the races of men in all time there were never two exact duplicates, and we can believe that no two flowers are ever so similar that a microscope would not show differences between them. We are as familiar with variations as we are with a clover leaf; but we have never been inside of them, never have realised what it means in nature's architecture *to vary a pattern.*

The extremes of such variation are called monstrosities. The Siamese Twins were joined to each other by a thick tube of cartilage, through which their vital organs were so closely connected that no surgeon dared cut them apart. They were very unlike their parents. The Bohemian Twins were a pair of women who had only one spine between them. When they died the courts had to decide whether the twins were one person or two persons. This two-in-one body bore no resemblance to its parents or ancestors. Peppino Magro, twenty-two inches tall when fully grown, and Kazanloff, nine feet, three inches tall, varied from their parents in stature. They were born with some peculiarity of a little gland which directed their growth abnormally. A baby that is born without arms, or with a jaw-bone growing in its body, or with a full set of teeth, or with a hairy nose and forehead, or with a tail, shows a decided variation from normal parents.

[1] Note for any critical reader: This chapter has little to say about the distinction between somatic modifications, recombinations of genes, and germinal mutations. These technical questions are omitted from so elementary a book.

Animal monsters are constantly being exhibited and reported: Siamese twins among fishes have been the special study of one French zoologist. Calves are born with an extra pair of little legs hanging from the shoulder, or they have peculiar heads and are called "dog-headed" or "human-headed." A cat has been born with only two legs, on which she learned to walk; and a lamb has lived without any legs. A stag may have one of its antlers growing downward.

Among plants there is no end to the monstrosities that are frequently seen. Ears of maize are double or distorted, or have unnaturally arranged kernels. A little peach sprouts from the cleft of a large one, or a kind of second orange may appear at the base of an orange. A bean, which normally sprouts with very large leaves, at the base of which are little insignificant scales, may show gigantic scales and no leaves. If we ask what caused these peculiar variations, we can think of only one answer: something abnormal occurred in the development of the egg. What does that mean? What are we talking about when we carelessly pronounce the words "change in an egg"? If I may judge others by myself, we are thinking of nothing at all. People spend intellectual lives, studying psychology or art or history, with no more curiosity about an egg than if it were a drop of water that may change into steam or ice according to the temperature. Yet a germ-cell is a compound of unexampled marvels, more intricate than the whole galaxy of suns and nebulas, containing in its deep recesses secrets which lie far beyond the reach of the most skilful user of a microscope. A germ-cell is life. We shall never know much about it until we have penetrated all the rest of the universe.

But something has been learned—enough to show in a general way the course of the evolution of life upon the earth. It is very recent knowledge, hardly seventy-five years old. Within those years all the understanding

of the nature of plants and animals has been revised by learning about "cells." Thirty years ago the study of these was largely devoted to the masses of them in tissues (called "histology"); nowadays university courses attack the cell directly; everything is cells, cells, cells. An old-fashioned person may grow weary of this chorus that perpetually wells from all our laboratories; but as soon as he discovers the reason for it he must sympathise. The study of the cell has given us the greatest revelation of how nature works in moulding life.

Recall that time when we stood within a clover leaf gazing through the crystalline walls of a cell, behind which surged the streams of protoplasm. We watched the varying grey mass of viscous liquid, within which we could faintly see strands of fibre, forming some sort of open mesh. It was a piece of life, complicated and specialised for its own duties. Its core was water and sap; around its walls, in the protoplasm, were the green sugar-making globes; the protoplasm flowed from point to point, directing all the details of a sugar factory. It could repair its own walls, summon water and gas, send out oxygen, ship its products out through connecting veinlets. It has a skill that lies beyond understanding. In other cells this protoplasm knew how to transform food and energy; in others it made the roofing material; in others it concocted oils or fats or colours. It transmitted orders to the workers in the pores and hairs and veins. Hence it is more than a substance that a chemist can analyse; it is beyond analysis. It is not a certain kind of material, any more than jelly-fish and lions could be called the same kind of animal material. "Protoplasm" is only a convenient name for our blindness when we look into cells. Since we cannot detect the differences, we give the name "protoplasm" to the living matter that we see.

If we had observed the protoplasm of the clover-leaf cell as clearly as the highest-power microscope

does, and had had a guide to tell us where to look, we could have distinguished in it a little body, no larger than one of the sugar-making globes, the "nucleus." In this small globule is contained the guiding power of the whole cell, as if it were the office of a factory. It is this mucleus which directs the birth of a new cell.

Are you at all startled by hearing about "the birth"? This cell that we are looking at—this subtle aggregate of powers—could no more happen into existence than a camel or a whale could, for it is an organised unit of life. If I see a hawk flying overhead I know that he was once an egg and was born. It is just as obvious that the cell was born. It must have grown out of a cell. which had grown out of a previous cell, which had grown from a previous cell. There cannot have been any gap in the series of descents from the time when life began on the earth. Every cell, in every leaf and muscle and brain, is the offspring of some previous cell.

The origin of a cell in a clover leaf cannot be any hit-or-miss process; a new cell cannot "just branch off somehow." Even a beet-sugar factory that man makes—a clumsy pile of apparatus for doing the simplest sort of crude work—has to be designed by an architect with elaborate fulness. There must be complete blue-paper plans, an engineer's care to have foundations solid, a builder's minute pains to have the walls kept plumb and the courses of brick level, expert work to make steel girders exact, expert manufacture of vats and engines, high technical skill to furnish spectroscopes and chemical reagents. If so lumbering an institution as a man-made factory requires all this provision, much more will the creating of so intricate an organism as a plant cell. Of all the secret processes in a cell not the least jot of a small item of one can be left unprovided for.

The specifications for a future cell lie in the nucleus. When this receives the impulse to reproduce its mechanism is set to work, and it operates its hundreds of minute

parts with an accuracy that is awe-inspiring to think of. So small is the space within the nucleus and so dim are the outlines of operations that no scientist could ever have charted the scene by himself. But after a generation of work the experts are now able to give us some pictures of the steps of a birth.

They tell us that in the course of half an hour or more the following programme is carried out. First the nucleus spreads out to occupy a larger protion of the cell. Several loops appear in the liquid; they grow shorter and thicker and become straight; they then arrange themselves in the centre of the cell, as if they were so many bits of a small thread, placed end to end in a plane. Each of them splits down its length into two equal parts, as if a fine knife had been driven through the bits of thread and had divided them all at one blow. Thus the original tangle of loops has been separated in an orderly manner into two equal sets of straight pieces. The two sets now draw apart, moving away from the equator of the cell toward opposite poles. Meanwhile the whole cell has been preparing to divide: a groove has appeared on its outside, as if made by a string that had been drawn tight around it in the same plane where the little bodies split within the nucleus. The groove grows deeper and deeper, till the cell is split in two. The result is two small cells, each composed of half of every detail of the previous cell, each with a complete equipment of cell life. These grow quickly to full size, and are now prepared to reproduce in the same way as often as they have orders to do so.

That brief sketch of cell birth may give a wrong impression by its comparison with "bits of a thread." Of course, the real processes, if our senses were fine enough to see them, would appear as a set of countless adjustments made rapidly with supreme nicety. And perhaps the crude sketch has made the reader forget the size of the space that encloses all the operations.

The whole cell is so small that it may not take up more than a millionth part of one leaf. Of the minute space in this cell the nucleus fills only a fraction. Even within the nucleus all the complexities of a future organism are arranged for in one small part of the space—that is, in the bodies that split apart. The mind cannot begin to comprehend such close packing of forces; it quits exclaiming about "marvels" or "unspeakable mysteries" because any words of wonder fall so far short of what we feel.

The best we can do is to accept the bare fact that in those infinitesimal loops at the limit of microscopic vision is packed the complete outfitting for the whole life of a daughter cell. These are called "chromosomes," a word that means "colour bodies."[1] Every one of the cells that make up flesh or wood or animalcules arose in this way by means of chromosomes. They can create a new cell that inherits all the peculiarities of the old one, and hence they are called "the carriers of heredity."

There are endless varieties of cells. The live bark of a tree is built of several kinds, each with its own individual sort of protoplasm to keep up its activities. Bone and mahogany are made by protoplasm that builds hard walls for its cells, and then dies. In the brain are cells where protoplasm keeps records of sensations and manages switchboards for sending messages to other cells. A nerve-cell is a long, slender fibre. In a cubic inch of normal human blood there may be seventy billion cells, fitted to do special chemical work or to rush as soldiers against invading forces. The small red ones are generated in endless billions by mother cells that live in the bones. There are cells that lead separate lives as individual animals—like an amœba, for example, which is a single cell that opens up any part of itself for food.

[1] So named because they were first made visible by colouring them with a stain.

Cells are of all sorts, of all degrees of complexity; but all alike originate by the mechanism of chromosomes.

Before we go on to describe the variations that originate in chromosomes it may be well to speak of a common misconception, one which used to mystify me. I refer to the use in older books of the word "simple" to apply to germ-cells. "Simple" means only that the cell is "single," that there is only one of it. The human eye is called "simple" in comparison with the multiple eye of a fly. In this sense we might say that Paris is a "simple" city and King Alfred a "simple" man, because the city and the king are not compound. A "simple" cell may be, potentially, as intricate as an animal.

Keep that statement in mind when you hear that every egg is a cell. A grain of clover pollen is a cell. Inside of this is a nucleus, within which are the chromosomes. They are what count.[1] They carry all the specifications for a whole new plant, for all the types of cells that are to form roots and ducts, and stems and leaves, and hairs and blossoms and future seeds. In them are, potentially, all the structures of the next generation, complete to every least item, such as making each hair taper to an end that is somewhat pointed, but rather blunt and irregular. The chromosomes are faithful agents, powerless to disobey, for carrying out these specifications. They cannot construct grass or gooseberries; they cannot construct another kind of clover; they can only reproduce a plant like the one from which they came.

This holds true for every egg of any kind of plant or animal. In every egg there are some chromosomes within a nucleus, and their development is all determined in advance: they are compelled to build their new life on the pattern of the parents. No earthly power can

[1] A cytologist would find this statement over-simplified, for there is no doubt that the other contents of the cell have their part in reproduction. See E. B. Wilson's *The Cell* (1925), Chapter IX.

reach inside the chromosomes and make a new pattern for them to follow. Nor is there any way of so altering a parent that its reproducing cells will create a different species of body. However much you may mutilate a clover plant or a fowl, if you allow the egg-making organs to work at all, they will produce the only type of egg that they are fitted to produce. They must make the identical kind of chromosomes that their parents made and that their offspring will make. The business of chromosomes is to reproduce by the given pattern.

Yet, in spite of this, their machinery is never precisely perfect. *It does sometimes vary the pattern.* That is *Variation.*

We know next to nothing about the reasons why chromosomes vary from their normal operations, but can only notice that they do vary. Their inexactness is not surprising. Indeed, the wonder is that in such intricate work as theirs they ever can follow the model as closely as they do. We should naturally expect that there would sometimes be slips or failures in the machinery.

Variations are sometimes spectacular, giving rise to a new variety of species. In 1791, on an American farm, was born a ram whose legs were so short and body so long that he was nicknamed the "otter"; he was valuable because he could not jump fences, and he became the founder of a new breed of sheep called the "ancon." Forty years later the same sort of thing happened on a farm in France. A ram was born with a large head, long neck and legs, covered with smooth, silky wool; he was the forefather of a new and valuable kind of sheep. Such sudden creations, or "sports," are decided alterations that chromosomes make in the pattern they are supposed to follow—"happy mistakes" we might call them. Such a mistake certainly brought joy to a breeder in 1889, who one day found that a young calf in his herd of Hereford cattle had no horns; it founded the race of "polled Herefords."

These great variations are celebrated because they were so useful to man and were as romantic as the discovery of a new diamond mine. Yet they show no more peculiar shifts in chromosomes than many cases that are only curious freaks of passing interest. Man has never taken advantage of the forgetfulness of a chromosome that did not put a tail on a colt.

There was once a set of chromosomes in an orange that did not put in any seed-making apparatus, and that ornamented the base of their work with a queer whirl. An orange-grower noticed this sport and liked it; since then the "navel" orange has been a famous fruit. A dozen years ago Professor Cockerell[1] saw on the American plains a native sunflower, a wild plant, that was red. Here was something new in the world, a sport produced by a chromosome that had transferred the colouring matter from the disk, where it belonged, to the flowers at the edge of the disk. So rarely is such a slip made that, with one possible exception, no other case was ever reported. Darwin exclaims thus about a sporting plum: "When we reflect on the millions of buds which many trees have produced before some one bud is varied, we are lost in wonder as to what the precise cause of each variation can be." To-day we may still be "lost in wonder" if we try to imagine just the motions that a chromosome would make in building a new variety of plum, for the motions and materials are beyond our range of imagination; but we can now understand in a general way that in the mechanism of chromosomes there may once in a while be a shift of gears, and that such alterations may be fortunate.

One of the most useful plants for man is wheat. Its chromosomes are restless and variant; one Frenchman cultivated over three hundred varieties. Though most of these sports show only slight differences, occasionally

[1] T. D. A. Cockerell, *Zoology*.

there is a large and decided one. About twenty years ago in Canada two different varieties were mated; the chromosomes were so stimulated to mix up and recombine their elements that a hundred variations resulted, one of which—it appeared on only a single stalk—proved to be a hardier plant with better bread-making qualities than North America had known before. It was named "Marquis." A century ago this fact of the sudden sporting of wheat was known; a famous Scotch grower[1] testified that he had never seen grain which had been improved "by cultivation," but only "by selecting the new varieties which nature occasionally produces, as if inviting the husbandman to stretch forth his hand and cultivate them." In 1819 he "observed quite accidentally a single plant of a deeper green and more heavily headed out"; this he cultivated, and it became one of the best kinds for the region where Walter Scott lived.

So far as we know, all improvements in domesticated plants and animals came about in sudden variations, sometimes by a long leap and sometimes by a great number of very short steps; they appeared as unearned gifts from the chromosomes. We have records of a golden-coloured grape that sprouted from a black variety in England, of "a multitude of varieties that sprang from one seed" in a French vineyard, and of new hothouse varieties that are produced "almost every year." Each kind of apple was originally a solitary sport, a unique product, made by changeful chromosomes.[2] No new kind of peach was ever attained by effort, but always by discovering a novelty hanging on a tree. If an agricultural experiment station should try for a century to train the

[1] Shirreff, of whom Darwin says, "A higher authority cannot be given."

[2] Such changes may not be an appearance of a character that was never in the heredity; they may be only "recombinations" of ancestral characters, in such a way that the new combinations can be inherited.

seeds of a potato, it would fail; its only hope is to be on the look-out for what the seeds have happened to bring forth.

Chromosomes tend to make some of their variations repeatedly. Everyone knows that most clover leaves grow in clusters of three, but that in any field there are several clusters of four and may be clusters of five or more. Men have always observed that some pigs are born with a solid hoof instead of the usual two toes; pigs may occasionally have a third toe, or a pair of bristly tassels under the throat. Most coloured animals occasionally have white young, and these albinos are often less hardy than the parents, being less able to withstand heat or poisons or parasites. In any flock of peacocks there may suddenly appear a bird of smaller size with black shoulders, as if the chromosomes of this animal were prone to make, every so often, this particular kind of variation. The shell of some species of snails regularly grows in the direction in which the hands of a clock move, but occasionally specimens grow in the opposite direction. Human chromosomes give a small percentage of us two-jointed fingers or freakish powers of multiplying mentally.

If only one double thumb or one four-leaf clover had ever been seen, we might suppose that chromosomes had strange independent powers of their own, that they were like people who enjoy playing a joke or inventing a novelty. In the same way a South Sea Islander who had seen only one motor-boat in his life would suppose that the engine had mental powers of its own and was a kind of harnessed demon. But any civilised man—though he may speak of an engine as "acting badly" or may swear at the "perversity of inanimate objects"—knows that an engine must follow the set laws of mechanics. Every biologist knows that chromosomes are absolutely bound by the fixed laws of physiology; however "comical" or "bungling" their work appears, they are just as passive organs as a heart or a blossom is.

And even when they produce a novelty their work is, more often than we think, of a routine sort, like putting colour in the unusual place or putting on a fourth leaf. The celebrated Dutch botanist de Vries warns us that when we see in a bed of white flowers one blossom with a bluish tint this unexpected blossom may not be a real sport. He knew how often the irregularities occur regularly. In his search for real sports he found a varying primrose that promised well; he observed its variations for sixteen years, and in 1903 published a big book on the subject. He believed that his primrose had sported into seven distinct new species and into many others that were less decided. He described "the very first moment of the appearance of two of the new stout species" and said that "they seemed to have inherited the capacity of producing in their turn new mutants." *Mutant* was his word for a new species that suddenly sprang into existence; on this idea of "mutation" he built a theory that was the talk of the learned world for twenty years. Yet those "new species" whose birth he celebrated have also sprung into existence in America, and have also sprung into existence in England, and perhaps have been born regularly at intervals for centuries, like so many five-leaf clovers. Possibly de Vries fell into the same trap that he warned us amateurs against. Thus we see that Variation is an extremely complicated matter, about which there is still much to learn.

You and I seldom take notice of differences between the parent and the young. Even the experts sometimes fail to find them; the goose, though domesticated for thousands of years, has shown hardly any changes. But almost always the close observer finds the variations, as this quotation illustrates: "Mr. Bates, after examining above a hundred of the big beetles, thought that he had at last discovered a species in which the horns did not vary; further research proved the contrary." If a specialist can make such a wrong supposition, surely the

rest of us need to see the universal truth displayed in a series of quotations from men who know by long study that chromosomes can never be trusted to be absolutely exact. "I have seen it gravely remarked that it was most fortunate that the strawberry began to vary just when gardeners began to attend to this plant; the truth no doubt is that it had always varied." Of course it was the truth; three hundred years ago some shrewd gardener "availed himself of the inherent power of variation possessed by the plant." All beans may look alike, even to the most sharp-eyed grower, but "after two severe frosts only three of the three hundred and ninety scarlet-runners remained, not even the tips of their leaves being browned; it was impossible to behold these three plants, with their blackened dead brethren all around, and not see at a glance that they differed widely in constitutional power of resisting frost." "The gold-fish, from being reared in small vessels and from being carefully attended to by the Chinese, has yielded many races." "Where flowers are grown by the acre for seed scarcely a season passes without some new kinds being raised." Naturalists tell us just as emphatically that *wild* plants and animals show the same tendencies as the domestic. The wild orange plants in the jungles of India have the characters of the bitter variety, "but occasionally wild oranges occur with sweet fruit." "The chestnut trees may possibly survive the present blight in New England, because there may be here and there one that contains a secretion which will kill the attacking fungus; there are such trees in Asia, whence the blight came." "Our common forest trees are very variable." "It is probable that all insects occasionally show some abnormality of wing venation." "The description of new mutant types in almost every plant and animal that has been carefully examined indicates the very general occurrence of definite mutations." The prevailing fact of variation is put thus emphatically by Wallace: "We

find no evidence of greater variations in domesticated animals than in wild ones."

Darwin, an exceptionally keen-eyed naturalist, often marvelled at the skill with which breeders of animals detected slight variations that were invisible to him: "In the great majority of cases a new character is at first faintly pronounced, and then the full difficulty of selection is experienced. . . . The finest powers of discrimination and a sound judgment must be exercised. . . . I have been astonished when celebrated breeders have shown me their animals, which have appeared all alike, and have assigned their reasons for matching this and that individual. . . . The best flock-masters do not trust to their own judgment or that of their shepherds, but employ persons called 'sheep-classifiers.' When the lambs are weaned, each in his turn is placed upon a table, that his wool and form may be minutely observed. . . . Those alone who have associated with pigeon fanciers can be thoroughly aware of their accurate powers of discrimination acquired by long practice. I have known a fancier deliberately study his birds day after day. . . . Sir John Sebright used to spend two or three days in examining, consulting, and disputing with a friend which were the best of five or six birds. . . . Wherever silk is produced, the greatest care is bestowed on selecting the cocoons from which the moths for breeding are to be reared. Near Shanghai the inhabitants of two small districts have the privilege of raising eggs for the whole surrounding country, and that they may give up their whole time to this business, they are interdicted by law from producing silk."

We know that only persons with inborn talent, trained by long experience, are fitted to judge at shows of dogs or poultry or cattle. These judges are experts in variation, and to them no two animals ever appear identical. Exact reproduction is never to be found. In the patterns made by chromosomes there is perpetual *Variation.*

CHAPTER VIII

HEREDITY

EVERY reader of this book knows that the sun does not move around the earth. Also he knows that the moon does move around the earth. These two heavenly bodies, which appear to be of the same size and to move in the same way through the same path over our head, are as different in size as a grain of sand and a tennis-ball, as different in motion as the second hand and the hour hand of a watch. The moon does what it seems to do; the sun is deceptive.

There are two principles in evolution which seem like counterparts of each other—Variation and Heredity. Heredity is like the moon—it is near to our common knowledge and it is what it seems to be. Variation is the sun of the system—much larger than it appears, more remote from our understanding, and deceptive in its motion. All evolution revolves around Variation. All evolution is determined by the fact that chromosomes never reproduce exactly. As you read this chapter and the next one, keep your mind on Variation as the centre of the whole theory. University teachers who have hammered away at this subject for twenty years testify that the minds of students are always forgetting that the prime cause is Variation. Many a university graduate, fresh from his course in biology, will falter and go wrong in trying to explain the subject because he forgets to start with Variation. That is the reason why Variation was described so emphatically in the previous chapter. It was put before Heredity and Natural Selection. Fasten your mind on *the variations made by chromosomes*. A

useful slogan among students is, "Keep your eye on the chromosomes."

It is small wonder that we all tend to put the explanation wrong-end-to. The whole world always had it hind-side-foremost until 1859, and in every-day life we invert the truth as naturally as we say that "the sun rises."

Consider a pair of examples. The first is the colour of the negro. I always used to suppose that Adam was a white man, that some of his white descendants migrated to Africa, that the first generation of them was tanned by the tropical sun, that their children therefore *inherited* a somewhat browner skin, and that the grandchildren were somewhat browner still, until finally the race became so thoroughly brown that it was black. I never asked myself, "How could sunburn be inherited?" When a man has learned to keep his eye on chromosomes he can see that no amount of tanning will alter the skin-making part of that mechanism. The second example is bow-legs. It is natural to take it for granted that about a thousand years ago Spanish men became bow-legged from riding horse-back, and that in the course of thirty generations of knights and vaqueros each child *inherited* the bow-legs that his father had acquired by clasping a horse for twenty years. We never inquire how this exercise of leg muscles could enter the germ-cell, then penetrate the nucleus, and then set up alterations in the infinitely delicate and complicated mechanism. The notion is absurd to anyone who will keep his eye on chromosomes.

Less than a century ago the whole world assumed that acquired tan and muscle-development could be inherited. The most learned scientists believed that if a man enlarged his forearm by labour or trained his fingers to write a good hand his son would in consequence have a bigger arm or write the same kind of hand. All the great naturalists of Europe thought that if a giraffe

continually stretched her neck for food the offspring would inherit some of the strength and stretching ability that she gained by this exercise.

This is a very common idea, on which we have all been brought up. We naturally take it for granted that if we train two generations of pointers the third generation of pups will inherit more ability to stand motionless, that if we keep the feathers plucked from ten generations of hens the eleventh brood of chicks will have scantier plumage. This common and natural idea used to be accepted as the theory that "acquired characteristics can be inherited." A "characteristic" means any item of the bodily or mental make-up, such as white hair, big biceps, thick fingers, weak lungs, keen sense of smell. It is the word that Darwin used, and is the natural one, but nowadays the scientists use instead the shorter word *character*. "Acquired" means produced in the body during its lifetime. Thus if a parrot's tongue is slit, or if a lion learns to live on vegetables, or if a blacksmith's arm is increased in size by wielding a hammer, the changes thus made in their bodies are said to be "acquired characters." The theory taught that if we cut off the tails of a male and a female cat their offspring might, as a result of the amputations, be born without tails. Even so late as 1887 there were exhibited at a Naturalists' Congress in Germany some kittens that were said to have been born with only stumps of tails because the mother had lost her tail by an accident—that is, she had "acquired the character of taillessness." And even the most famous promoter[1] of the cell theory took the exhibition seriously! Scientists gravely listened to stories of how a duelling scar was inherited and how a man's frozen thumb caused misshapen thumbs in his grandchildren.

All through the nineteenth century the scholars

[1] Virchow. See Weismann, *The Evolution Theory*, ii. 64.

discussed the question, "Can scars be inherited?" The greatest German philosopher argued before Darwin was born that they could not be, and in Darwin's old age the greatest English philosopher was still arguing that they could be. The debate might have gone on till doomsday if a common-sense biologist named Weismann had not cut off the tails of a pair of mice to see whether their young were born without tails. Instead of "thinking" how heredity might work Weismann, like Columbus, sailed into the facts. The little mice were born with full-length tails, which were promptly amputated. The whole litter of this second generation was carefully brought up and allowed to breed together. All of the third generation were born with normal tails, which were at once amputated. Their young of the fourth generation still failed to inherit taillessness, and their caudal equipment was cut off. There was no inheritance in the fifth or the sixth or the seventh generation; there was no slightest evidence that acquired characters can be inherited. The experiment was continued for twenty-two generations, and the last litter of mice had tails just as long and perfect as the first. The 1,592[1] bodies of the twenty-two generations were preserved in alcohol, and are to-day a monument that marks a turning-point in our ideas about heredity.

The second chapter of the mouse-tail story is as significant as the first. When Weismann published his result, the scientists did not credit his report as truth simply because it was to be found in print. Before they believed it they repeated the experiment to see that it was correct. Reverend professors in several European laboratories devoted themselves to amputating tails of many successive generations of mice and rats. Not one of them found any proof that acquired taillessness could be inherited. Since that day no one has found any

[1] Herbert E. Walter, *Genetics.*

such proof, and now the scientific world has abandoned as unproved the idea that any sort of bodily mutilation can be inherited.

This change of opinion is not founded on logic. So far as logic goes, we could reason that the amputation of a left leg would give the body a shock, that this shock might be transmitted to a germ-cell, and might there kill that part of a chromosome that was commissioned to build the left leg of a child. Nature *might* have made the reproductive machinery in that way. But she *did* not. No credible case has ever been found of a bodily injury being transmitted to offspring.

Yet some cats are born without tails. Why? Because the chromosomes in the single cell where their life began had no tail-making apparatus. The young of Manx cats and wild bobcats have no tails because those races are tailless; none of their kittens can have a tail unless some disorderly chromosome varies so much as to form one. On the other hand, every Maltese cat or tiger must inherit one unless some chromosome,[1] by a freakish variation, fails to provide it. All depends on chromosomes. If for a century breeders should cut off the tails of bull-pups or clip the ears of fox-hound pups the heredity would not be affected; the chromosomes continue, undiscouraged, to make the same long tails and ears. Although aristocratic Chinese women have deformed their feet by binding them in every generation for two thousand years, the child that is born to-day has normal feet, formed according to the pattern that chromosomes faithfully follow.

That is the business of the germ-cell—to reproduce the ancient model. Though there is always some slight variation, and may occasionally be a big one, yet the descent always tends to persist unchanged.

If the chromosomes that formed a certain man

[1] Of course, monstrosities may sometimes be caused by faulty development in later stages of the embryo.

unkindly gave him a deformed joint at the base of his thumb, they may pass on the bad trick to the next generation of chromosomes, which may follow the new model, and so a son may inherit the deformity. But if the man slashes the thumb with an axe, the wound produces no effect on the chromosomes of his germ-cells, and the big scar cannot be inherited.

You may plant big potatoes in poor soil and dig small ones; then for a dozen more seasons you may plant the descendants there and find them always small. But plant the next generation in good soil; you will have the same large ones with which you started. If a quick-growing young pine tree is transplanted to the top of a rocky mountain, it will become small and wizened, leaning away from the prevailing wind, unable to grow an inch a year in height; and the seeds that sprout from its cones in that neighbourhood will form dwarfed and distorted trees. But the chromosomes have not been made correspondingly lopsided or shrivelled. If you plant one of the seeds in good lowland soil it will spring into straight and prosperous growth. The "environment" on a mountain is unfavourable, and will alter every generation of trees that grow there.

Suppose that you captured an owl, a flesh-eating bird, and fed it on grain, as a famous English physician once did; if you could keep it alive on that diet its stomach might be somewhat altered after a couple of years. But when the owl laid an egg the chromosomes would be the same unchanged mechanism, and would proceed to create exactly the sort of stomach with which the parent was born. The character of grain-eating—like the dwarfing of the pine tree—is acquired by the body, and a change of that sort has never been known to be inherited.

That word "acquired" is often misleading. We usually think of some ambitious or aggressive act when we hear it, such as "acquiring a lot of money, acquiring a big reputation." But there is nothing aggressive in

the technical meaning. A plant or animal does not make any effort to get hold of a character. By some accident or disease, by some action of climate or food or mental stimulus, a change is forced upon it by an outside influence. And this change is always in the body-cells—in the muscles or bones or nerves or membranes.

Within all this aggregation of body-cells lie the germ-cells, very distinct and leading a very separate existence. They were set apart when the egg began to develop. Near the beginning of every person's life the germ-cells for forming the next generation were set aside, in a secure place, where they could lie dormant until the body had grown to maturity and had set them in action. From that early moment of embryo life on to the end the germ-cells are beyond the reach of any ordinary outside influence. No specific character can be forced upon them.[1]

Nowadays it is known that some bacteria are so small as to be able to reach the germ-cells and affect them. We know, for instance, that the spores of a silkworm parasite penetrate eggs that are still within the caterpillar's body, develop with the embryo, and so afflict the young with the disease. The germ of syphilis is so small that it may be transmitted in the same way. Yet even such cases are not inheritance, because they are influences from outside the germ-making apparatus. Beyond that moment when the original cell has divided, the individual has begun its separate life, and any change is an acquired character. This is not a matter of definition or stickling for a point; it is a fundamental distinction. Anyone who cares to keep his eyes on the chromosomes will see it.

In no ordinary case can disease or alcoholism or

[1] The paragraph does not mean that germ-cells cannot be affected in any way through the body; it means what the last sentence says, that no *corresponding*, heritable variation can be induced in the germ-cells by an outside influence.

any form of debility acquired during an individual's lifetime be specifically inherited by his offspring. And any men who build theories on a few apparent exceptions must nowadays speak in different terms from those which were used thirty years ago. No modern scientist claims more than this: that a profound change in the body-cells might be communicated to the germ-cells, and so might stimulate or interfere with them. Thus an outside influence might throw the chromosomes into confusion and cause defective work. Or if a chromosome is carrying two patterns, the first of which would normally be suppressed, an outside influence might be a disturbance that could cause the first one to develop, or it might act as a kind of trigger that would throw into gear an old pattern which had lain dormant in the chromosomes for hundreds of generations. But no outside influence can remodel the machinery or add a new part. No outside influence can produce a *corresponding* effect in the germ-cell, any more than the carbon on a spark-plug can make a carbonic engine. Darwin expressed the effect of an outside influence thus: "The nature of it is perhaps of no more importance than the nature of a spark in determining the nature of the flames." Darwin was always sceptical about the inheritance of acquired characters, and did not base his theory on it, though he is often accused of doing so.

The great body of evidence coming from the laboratories to-day shows how independent germ-cells are of the body-cells, what a detached life they lead, and how they work by a routine process. Anyone who could for a few minutes look with his own eyes at the "mechanism of heredity" that Professor T. H. Morgan has demonstrated by experiments and studied under his microscope would never again be hazy about acquired characters. This man — and dozens of other recent investigators—has taken the guesswork out of chromosomes. What Darwin did not live to see, what Weismann

saw dimly and speculated about, he now pictures for us in books[1] that all may read. In nuclei not one-ten-thousandth of an inch in diameter he has seen the operations of the beginning of a new life in a cell. He has seen chromosomes intertwine, exchange parts with each other, and move asunder; he has seen them solitary and in equal pairs and in unequal pairs; has seen them split apart; has watched their actions vary with temperature and observed their regularity. He has seen the chromosome that determines whether the new animal shall be male or female.

All this is wonderful enough, but he has gone much farther. He has proved with painstaking care that certain parts of certain chromosomes have their particular jobs. (These parts are called "genes.") He has been able to predict from the way chromosomes join with each other whether the egg will develop into an insect with shield-shaped wings or forked wings, with white eyes or red eyes. He has found that sometimes the work of many genes is necessary to make some one slight character. After breeding millions of little fruit-flies through hundreds of generations and tabulating the results, he and other investigators were able to make a map of the main parts of the chromosomes, which were shown by four parallel lines in a diagram. Well may an admirer of their work say of these lines, "It is doubtful if in any book there may be found four straight lines that mean so much."

No scientist of standing to-day can conceive, in view of all this exact knowledge of how chromosomes behave, that any particular change made in any creature's body during its lifetime can be passed on to its offspring. Heredity is now known to be a matter of a succession of germ-cells. They are the means—the only means—of carrying on the pattern of life from one generation to

[1] *The Mechanism of Mendelian Heredity* and *The Physical Basis of Heredity.*

the next. Every germ-cell is born directly from a previous germ-cell, of which it is a reproduction. There can never be any gap in the succession. Here is a stream of life that has flowed continuously from the first nucleus to the last. It is this unbroken stream of heredity that nature cares about. The trunks of trees and the bodies of sharks and stags are only contrivances to keep the stream flowing, only a series of reservoirs for germ-cells, a series of homes in which germ-cells may be protected until they can reproduce.

Picture to yourself a stalk of maize that was cultivated by a savage when Athens was young. Its sturdy stalk mounted, its splendid leaves were thrust out, and its roots spread vigorously. When its whole body had developed it flowered at the summit in a tassel, producing innumerable minute grains of pollen. Every one of these was a plan of the entire plant—root, stem and blossom—with provisions for rebuilding an entire set of the hundreds of millions of varied sorts of cells. Below the tassel had grown another set of flowers (clustered about a cob and covered by layers of husks), each of which sent out a long thread to the end of the cob; there the threads emerged from the husks and hung in a silky cluster. On to each fell pollen grains. The fortunate one in each case found its way to the hollow core of the thread and descended the whole length, to where at the base an egg was awaiting it, an egg that also had provisions for the whole organism of a stalk of maize. Into this it made its way, and the two cells combined into one. The new cell divided, mingling the chromosomes from the two parent cells and sending equal parts to each of the new ones. Each of these in the same way divided equally its inheritance. From four to eight to sixteen to thirty-two to the end there was the same equal division of the inheritance. Thus was formed an embryo of a new stalk of maize. This was the treasure for which the plant had laboured. The rest of the plant's life was devoted to

building around the embryo a store of rich nourishment for its next stage of life. The seed was complete—a kernel of maize. The parent died.

Through the winter the embryo slept. Next spring, when warmth and dampness had stimulated it enough, it resumed the multiplying of its cells, each of which received that equal inheritance from tassel and silk—each one of the vast aggregate that was to labour underground and in the pith and in the sharp edges of the leaves of the new plant. All their combined labour through the second summer was for one result—to build a home for the germ-cell that was to continue the stream of descent. This was a part of its parent cell, a veritable piece of it, and it kept the unbroken stream of life flowing through the summer of plant growth and through the winter of plant death.

Its own self was in the tassel and the silk of the third summer and of the fourth. And so long as that species of maize lives every kernel will be a link in a continuous chain of germs back to the beginning of the species. And the first cell of maize that ever lived must have been born directly from some previous cell. There never has been—there never could have been—any gap of a single link in the succession of cells from the beginning of life on our globe. That is the "germ-plasm stream." That is heredity.

It is the force that tends to make life durable, persistent, unchanging. No wonder that Weismann exclaims about "the enormous duration of the constancy in a species." He was speaking of some butterflies that have maintained, in an unchanging form, a germ-stream for fifty thousand years. Even that period is short compared with another that we have heard of in a previous chapter—an unchanging succession of germ-cells in a tree for several million years. One genus of little bivalves (*Lingula*) has lived almost unchanged through nearly the whole geologic record to this day—so long a duration

that estimates of it vary from twenty million years to two hundred million. Heredity always tends to preserve the same forms for ever.

The persistent power of the current of sameness may seem even more striking if we turn from the inconceivable stretch of ages to some petty subject, say pigeons. These have been domesticated for several thousands of years and have varied in the most extreme, sometimes outlandish ways; but if we mate two of the artificial varieties, we shall see young that are like their ancient ancestors of Asia. Before the Babylonian Empire arose there had been set up in the chromosomes of the wild rock-pigeon a design for bodies of a certain size and shape, covered with feathers in a certain pattern; and all the while they have carried it in the germ-stream, latent and concealed; now, when they are disturbed, back they go to the model that is native and deep-founded. Even the useless hairs on our arms are always set according to a certain ancient, established pattern.

Do you complain that this is confusing? Do you find fault because the chromosomes are one minute described as unchanging and in the next minute as ever-changing? You well may complain, for the statements seem contradictory. The contradiction, however, is the fact of nature. Chromosomes have those two opposite qualities. On the other hand, they are never absolutely precise and may vary most wildly; on the other hand, they may return from their fluctuations to their original design and reproduce it unswervingly for ages. Their variation is a fact, which was exhibited at length in the preceding chapter. Their unswerving fixity for long periods is equally a fact. If a palæontologist takes a rapid glance at the record of all life for fifty million years, he is impressed by the variation; and yet he is the very man who can give us the most striking examples of unvarying heredity. If a naturalist observes poplars and swallows from year to year, heredity seems the conspicuous feature;

and yet, if he is careful enough, he will see perpetual variation. These are two inseparable truths, as opposite as the foundation and the roof of a house, and not any more at odds with each other.

They will be reconciled in the next chapter, on Selection. When we have understood each truth separately, and have then understood how they co-operate with each other, we shall have the secret of evolution.

Before we conclude the chapter we should remove from our minds a doubt that is lurking there. "How can it be," our sceptical brain keeps asking, "that the intricate pattern of heredity for a whole animal is carried in the minute space of the chromosomes?" We cannot conceive that the whole of a big organism is all represented and provided for in some microscopic beads on a thread.

The only trouble is with our brain, which is to the last degree gigantic and gross in its ideas. We cannot realise how huge and crass are our notions of matter as compared with what is known in the modern laboratory. If we adjust our brain to the facts of recent physics, a chromosome will seem as big as a palace, a roomy place for the architects of anatomy.

Begin the adjustment by picking up a ruler and seeing how small a distance an eighth of an inch is. Take half that distance, not a pinhead's width, and imagine a cube each side of which is one-sixteenth of an inch long. Does it seem a small space in which to stow a life-making apparatus? Only because we are like the towering creatures that grinned at the tiny six-foot Gulliver and wondered how blood could circulate in so small a heart as his. They were only six times as tall as Gulliver. If they had been a thousand times taller still they could barely have seen the speck of a human being, and would have found it impossible to believe that in him were capillaries and brain-cells. They would not have had imagination enough. If we can be unlike the giants

and can stretch our minds into the realms of the microscope and beyond, we shall have no more scepticism about the capacity of a chromosome.

Descend into this sixteenth-of-an-inch cube, which we will suppose is filled with human blood; become, as you were in the clover leaf, one-ten-thousandth of an inch tall. You are in a whirling world of twenty million disks. Most of them are of a yellow colour (the "red corpuscles"), with a diameter three times your height; each is an elaborate chemical apparatus for distributing oxygen. It is a large, coarse structure. If it were a person, it could not begin to see a molecule of the protein in its system, for it is twenty-three thousand times as wide as that molecule. It is massive and coarse and of vast size. If we wish to descend in matter until we can see something that is slightly refined, we must grow very, very much smaller, until finally we are far within the red corpuscle, and a molecule looms large before us. Even here we are disappointed, for we perceive that the molecule is massive and coarse, made up of swirling atoms. At this stage of our journey we are prepared to believe that the mechanism for making an elephant might easily be arranged for in one molecule. We must reduce by a tenth until we can pay proper attention to an atom. Lo and behold, it is massive and coarse! A physicist has written about *Exploring the Atom*, and if we wish to explore it we must reduce our size, and reduce, and reduce. Its diameter of one-three-hundred-millionth of an inch is now an illimitable field for our straining eyes. At length we see the electrons darting with fearful speed in their assigned orbits within the atom. And they have plenty of room. They are as remote from one another in proportion to their size as the earth is from the other planets. The mind can endure no more. It reels as it tries to apprehend the spaciousness of an atom.

When a person returns from such an expedition

to this our region of human sensations he has left his scepticism behind. He can exclaim with Hamlet, "Oh, God! I could be bounded in a nutshell and count myself a king of infinite space." Any space that our mountainous minds can conceive is more than is needed for the mechanism that nature contrives to carry on heredity in chromosomes. We gain in another way by such an expedition: we no longer object to calling chromosomes a "mechanism." That is an ugly and untruthful word if it suggests the coarseness of steel and steam; but now we know that it is only the organised powers, working by nature's laws, which convey from generation to generation, in the spacious chambers of a chromosome, the hereditary characters of a race of plants or animals.

CHAPTER IX

NATURAL SELECTION

I. *Sifting Out the Unfit*

In a school of salmon running up a turbulent river and leaping waterfalls to spawn there are some that were born too weak for such a severe test. These cannot endure to the end, and so they fail to propagate. If a hundred acorns are lying in the soil of a vacant spot in a forest they are not all alike; some have a weaker apparatus in their nuclei than others. When these sprout they are doomed to failure; for the trees from other acorns can put out roots and climb for sunshine somewhat faster. So always in the struggle for existence: weakness is not excused and can never endure; it disappears.

Of all the young of any species born on a certain day a few are exceptionally well fitted to survive, some are moderately fitted, and many are not quite well enough fitted. Of course, there will be casualties that come to the well-fitted and ill-fitted alike; lightning may destroy the strong and the weak indiscriminately, and enemies may sometimes have better luck against the strong. But otherwise, and in the main, variation has doomed a few to survive through a long fight, and many to be emancipated by early death. Survival or disappearance is principally a matter of variation in chromosomes—often a very slight difference. A little more length of wing, a little less weight of bone, a little—only a little—larger breast muscles may be

the difference between life and death in securing food. A slightly thinner shell of a seed may mean that the germ can sprout a little earlier, and get the start of others and survive them; or it may mean that the germ cannot survive the rigours of winter, and so will perish.

We know by actual measurements that all birds do vary in structure and power. "A variation of from fifteen to twenty per cent. may be ordinarily expected among specimens of the same species and sex, taken at the same locality."[1] And we know, furthermore, that variations much less than that may preserve from death. A captain of a ship in the Atlantic once made these two entries in his log when he was one hundred and sixty miles from land: "A great many small land birds about us; put about sixty in a coop, evidently tired out. . . . Over fifty of the birds died, though fed." They had been blown to sea while migrating, and only one-sixth of them had power to survive. A flock of one hundred and thirty-six sparrows, driven by a hard wintry gale, exhausted and numbed with cold, were once taken into a laboratory of Brown University. In spite of the best care sixty-four died. Accurate measurements were made of the living and the dead; tabulations showed that the dead were (1) slightly larger, (2) slightly heavier, and (3) had slightly shorter breast-bones. That is, those birds which had weaker breast-muscles in proportion to their weight could not endure the storm as the others did. In this case the difference between life and death was a difference of only one and one-third per cent. in the proportions of parts of the anatomy. Such variations, and much greater ones, are always to be found in a flock of wild birds; the favourable variations, will, in the long run, survive.

This fact that only the best adapted plants and

[1] Quoted in Wallace's *Darwinism*, from which come the data for this paragraph.

animals can live is called the Survival of the Fittest. Or since nature seems to "select out" the unfit and remove them from the struggle, the process is figuratively called Natural Selection—the name that is now in more common use. It is a name that misleads the unwary.[1] Nature is not a breeder and does not "select." What actually happens is that the less fit do not survive, while the more fit, or the fittest, do survive.

What will be the result of natural selection as it operates unswervingly through the centuries, always removing some variations and leaving others to reproduce? The answer is not easy to read in nature, because most of the results are brought about very slowly and were fixed long ago. But we can see an illustration of one part of the process by watching another kind of selection in artificial conditions. We can see how breeders of animals and growers of plants select variations for a series of generations. They work on a principle opposite to nature's, but they can give us the clue to natural selection, just as an artificial electric spark in a laboratory gives the clue to understanding a stroke of lightning that is formed by nature in a very different way.

A breeder selects variations for his human purpose —often a freakish one—of securing a result that has more meat or more expanse of petals. What we can see in his process is *a series of variations that are inherited and that result in a different kind of creature.* That is what we need for an illustration, because that part of the process is what occurs in nature. But we can use nothing more. The breeder and the breeder's purpose are utterly different from nature.

[1] Darwin coined the phrase as a kind of parable, in which nature is represented as "selecting" the best variations, as being a kind of breeder. Though he defined it carefully as including both "preservation and destruction," his parable has always confused literal minds. It misled John Burroughs so completely that he accused Darwin of being anthropomorphic!

2. *Artificial Selection: Preserving the Unfit*

The wild rose of Scotland has only one set of petals, arranged in one flat disk; it is a single flower. The idea once occurred to a Scotch florist that this blossom would be more beautiful if it had more petals, if it were double. His way of operating is an example of all those ways in which plants and animals can be adapted to man's fancy if the unfit are allowed to survive.

He did not begin by tampering with any seeds or blossoms; he did not do anything to any plant. He simply examined a great many flowers. Of course, he found that heredity had been making the blossoms all very much alike; all were single and five-petalled, similar in size and colour; he might have looked at thousands of blossoms before finding a variation from this pattern. But he knew that variation is bound to occur, and is bound to be discovered by any persistent searcher. He persevered till he found a blossom that had one extra petal, which was growing inside of the regular five. This sporting flower he marked, and in the following autumn preserved the seed-ball. So much for the variation part of the programme.

The florist knew that any such variation, even if it is abnormal, may be inherited. Next spring he planted all the seeds, and in the summer scrutinised the flowers. Three of them had inherited the extra petal. All the normal blossoms he destroyed, and next spring planted the seeds from these three unnatural ones. Ten blossoms inherited the extra petal. To an impatient man this is not much of a result for three seasons' work, but the gardener was quite contented, knowing nature's ways and knowing that it takes a little time to break up the habits of long ages of inheritance of what is adapted to the struggle for existence. Next year a number of his blossoms showed a whole extra row of petals, and the doubling was under way. Within ten years he could show

in his garden a flower that had six rows of petals. In so short a time had the pattern of the chromosomes been altered and a new one substituted. The double flower now had a changed heredity apparatus with respect to the number of petals ; this followed the new model, and has regularly produced, generation after generation, to this day, roses with many rows of petals.

But it is artificial, made by the fostering care of man. If it were turned out to shift for itself in nature's struggle for existence it would probably prove unfit and would perish.

That process of making a new kind of blossom is always the course of artificial selection. Man cannot begin the operation. Nature has to make the beginning. In some egg it happens[1] that the chromosomes are somewhat erratic, that they depart from the ordinary model. Why they vary no scientist knows—possibly no scientist will ever know. We can see the effects and can take advantage of them, just as an animal trainer can see the effect of a whip or a reward of food, though he never expects to know what makes the cells in the animal's brain behave as they do. We know that there is a complicated mechanism in chromosomes which never works with absolute precision, and we can see the results of their varying. That variation arises, suddenly appears, in a flower or a nose or a leg. When it has appeared we know that it is an alteration in the germ-stream of life, and so can become an inherited character if it is carefully preserved. We can thus manipulate heredity. This finding of a variation and then developing it by preserving characters that are adapted to man's wishes is artificial selection.

[1] Of course, nothing can "happen" without a cause. Every "chance" variation was produced in accordance with fixed natural laws. But we know nothing about the cause. When a scientist uses such words as *happens* or *by chance* or *fortuitously*, he always means "produced by unknown causes." See Section 5 of this chapter.

The human race was practising selection before the dawn of history. The earliest lake-dwellers in Switzerland selected variations in wheat and kept alive artificially a plant with plump grains that could not maintain itself in the struggle for existence. The earliest North-American Indians must have lived on the small kernels of a wild plant, in which they detected small variations; they selected the larger kernels for planting and developed maize. So long-continued was the selecting in these cultivated cereals and so far were they trained away from the original forms that now the botanist cannot tell from what wild plants they descended. And the variation is not at an end. To-day more than ever the agriculturists are noticing variations, selecting them for food values, and shielding them from the struggle for existence.

All our grains have been found by the same process, all the vegetables in our gardens, all the fruit trees, all the cultivated vines, all our beautiful garden flowers. Everywhere in the world to-day men are looking for variations as if they were prospecting for gold. They can no more make variation than they can create a precious metal; they can only seek for the gifts which the chromosomes have created here and there. To be sure, a gardener who wants variations in a wild plant may stimulate them by putting the plant in richer soil; but this is only hastening the variations or setting them free. Nothing but chromosomes can originate a variation. The first step of all selection in garden vegetables or trees or flowers must be to search for what some unknown power has made. A variation may be a great leap to something startlingly new—like the Red Astrachan apple—or it may be an infinitesimal step; but, large or small, it is caused by some sort of change in the chromosomes of the germ-cells.

When variations are closely observed in a plant and carefully selected through many generations they may be led into extremes of size and shape. The species

of one genus (*Brassica*), which still flourish in their wild state as insignificant little weeds, have been worked into a great variety of vegetables. One of them has been developed into a cabbage, the head of which is unlike anything in nature, and into a cauliflower, and into brussels sprouts. A second species has been selected along two lines: at the end of one is the turnip root, and at the end of the other are the oily seeds of the rape. A third species is mustard.

We all know what selection can do with flowers. It brings a yellow single flower from Brazil to France, doubles it, increases its size, and gives it all the forms and colours that are annually shown in exhibits of dahlias. Artificial selection takes a Chinese daisy and enlarges it to a mass of yellow bloom, a chrysanthemum, twenty inches across.

Cabbages and chrysanthemums are adaptations to the wants of man, but not to the struggle for existence. They are flabby, unnatural plants that can live only when they are removed from the competition of nature—from natural selection.

As with plants, so with animals. Before history began men had been selecting, almost unconsciously, the differences in dogs. By the time the records open men had many kinds, most of which could not have survived in the struggle for existence. There were slender hounds for speed and silky ones for pets. Man has manipulated the race as if it were so much clay, fashioning now a little helpless, hairless creature, now a squatty fighter all front legs and jaw, now a big friendly brute with a woolly coat, otter-hounds that have developed quite a web between their toes, a collie that has become highly intelligent, a stupid Chinese dog that is fed on vegetables and is used for food. We can set no limit to the moulding of animals that may be possible in the future. Horses have been shaped into greyhound forms for racing and into almost elephantine forms for hauling

drays. Pigeons have been bred with monstrous tails, with enormous "pouting" breasts, with long wattled noses, with beaks so short that the young cannot peck their own way out of the shell. Pigs have been made so fat that they are no longer like real animals, but are a sort of meat-factory on legs so short as hardly to keep the body off the ground. Man has gone even farther than this in opposing the course of nature; he has preserved for his amusement demented mice that spend their lives in whirling round and round; he has fostered disordered birds that "tumble" in the air.

Not all of these artificial creatures are weak. Darwin warns us that "we must not overrate the difference between natural species and domestic races; there is no palpable difference between them. . . . Domesticated races propagate their kind far more truly, and endure for much longer periods, than most naturalists are willing to admit." The bull-dog and the game-cock are certainly strong, and some cultivated plants are hardy if left to shift for themselves—buckwheat, for instance. But the bull-dog could not run down prey nor the game-cock scratch for food with his spurs if they were turned out to compete for a living in nature. It is not a matter of "strength" or "weakness"; it is a matter of being adapted, fitted. The strength of the fiercest bull-dog may not fit him to survive in nature; whereas the flabby "weakness" of a parasite may fit it admirably to survive.

All artificial selection—though opposite to nature in purpose and result—shows strikingly one element in natural selection: that certain types of variations are inherited, and that the inherited characters can increase by further variation, and that by selecting a series of such inheritances a plant or animal can be gradually altered into a new form of life. Every organism is plastic material that can be moulded by selection. But selection merely takes what nature provides in the form of variations. It creates nothing itself.

In the short time that man has been systematically altering natural forms he has never made such transformations as putting horns on pigs or shifting eyes to shoulders; but within limits he can decide what he wants and can then build to attain it. He can shape the comb of a cock, or the shoulder or the eye of a cow; he can alter the grain of the meat in a hog or remodel a canary's head. A successful breeder has a "prophetic vision," and that which he foresees he can make by selecting the variations that germ-cells create.

Artificial selection is not limited to animals that have been long domesticated; it is a process that is always seen when man breaks into the struggle for existence at a point where nature was never interfered with before. One experimenter[1] bred some little fruit-flies that showed slightly abnormal veins in their wings, removing from each generation those that were normal and allowing the abnormal to breed. In the sixteenth generation all the young were born abnormal, though in nature only one in three hundred is abnormal. Then the experimenter reversed the process. Starting with an abnormal pair and removing—"selecting out"—all the flies born with abnormal wings, letting those that were normal breed, he produced a sixth generation that was one hundred per cent. normal. By selecting for twenty-two generations he had made a round trip in variation.

When successive generations of young flies are carefully observed many kinds of variations are seen: some have limber wings, some have short wings, some have poor eyes. The new forms are not caused by artificial conditions, but are such as frequently appear in nature. They are healthy and will breed if they receive food. Why, then, do such forms never breed in nature? "Wild rabbits," says Wallace, "are always of grey or brown tints, well

[1] Frank E. Lutz, *Carnegie Publication* 143. This report is illuminating and significant.

suited for concealment among grass and fern. But when these rabbits are domesticated, without any change of climate or food, they vary into white or black, and these varieties may be multiplied to any extent, forming white or black races." These white and black colours are not new characters caused by putting wild animals into pens; they are variations that continually occur in nature. Why, then, are white and black rabbits never found in nature?

Guinea-pigs normally have three toes on each hind foot, but once in a great while a specimen is found that has four toes on one hind foot. Such a rare animal has been bred; all the offspring that did not inherit the fourth toe were selected out; all that did inherit were allowed to breed. In the fifth generation ninety-seven per cent. of the young had four toes on *each* of their hind feet.[1] Why has no such race developed amid the struggle for existence?

The variations that have been described occur repeatedly in nature, but regularly disappear. Does this, then, mean that nature never tolerates variations and never practises selection? The answer is in Section 3.

3. *Natural Selection: the Survival of the Fittest*

The man who made "the round trip in variation" of fruit-flies has observed in another set of experiments[2] what happens to variations in the struggle for existence. He studied crickets on a sand-bank which formed a small peninsula. He collected specimens in four places: (1) on the mainland, where the soil was good; (2) at the base of a sand-bank, where the soil was poor and sandy; (3) in the middle of the narrow sand-bank, which ran out seven hundred yards into the water; (4) at the tip of the

[1] W. E. Castle, *Carnegie Publication* 49.

[2] *Carnegie Publication* 101: *The Variations and Correlations of Certain Taxonomic Qualities of Gryllus*, by Frank E. Lutz.

sand-bank, where there was no soil, but only pure sand. He measured on every female cricket the length of the egg-laying tube, the "ovipositor," that protrudes, long and prominent, from the end of the body. The average length of the ovipositor on the mainland was eighteen millimetres (eighteen twenty-fifths of an inch); the average length at the base of the sand-bank was nineteen millimetres; in the middle of the bank nineteen and one-half; and at the tip twenty. The varying lengths were neatly assorted for these small differences. Here was a most curious proof that some kind of selection had been made—as obvious as if you should enter a room and find four piles of firewood neatly sorted out according to lengths. Such assortment could not be an accident. No more could these crickets merely happen to be arranged in groups; for the same measurements could be found year after year; the crickets do not migrate much in any season, but inhabit their regions for generations. Some force had been selecting. It must have been a very discriminating force, for it worked with differences of one-fiftieth of an inch.

If you asked a savage what did the selecting he would reply that some spirit, some sort of intelligence, had been herding the crickets into bunches. But the experimenter has found no sign of any spirit. If you ask the first intelligent, non-scientific man you meet, he will probably say, "Oh, the rich soil makes ovipositors fat and short, while the sand makes them long and lean." The intelligent man is giving the answer that seems always to spring up in the human mind—the idea that the environment causes changes and that these acquired characters are then inherited. Even trained minds that know an outline of evolution show a strong tendency to slip into that baseless, impossible explanation.

Only by keeping our eyes on the chromosomes can we hit the truth. Of course, the truth is that all such selection must have begun with germ-cells. The length of

egg-layers is very variable. In other localities crickets thrive with an implement only fourteen millimetres long; and where the average of the population is nineteen millimetres, no two specimens will have ovipositors of exactly the same length. That variability is the beginning of the right answer. The next part is readily found by looking into the struggle for existence of crickets. In the autumn they lay their eggs in the ground: in one locality fourteen millimetres is deep enough (supposing for convenience that the depth of the hole equals the length of the egg-layer), but on this it is not nearly deep enough; even on the mainland an egg buried only seventeen millimetres may be destroyed during the winter. *A mother who buries her eggs less than eighteen millimetres may not have offspring next year.* In the middle of the sand-bank the egg must be slightly deeper if it is to hatch; in the sand at the outer end no young will survive if the mother probes less than twenty millimetres.

The answer is complete when we inquire about heredity. If any germ-cell fails to produce a long enough ovipositor it will not survive in daughter cells in the germ-plasm of the next generation of crickets. Every mechanism that produces a proper length has a good chance to survive in the next generation. All the germ-cells of the next generation which are true to their inheritance will have a good chance to survive; *and all that do not follow the successful model will perish.* The winter's cold selects germ-cells more neatly than if it were intelligent.

To be sure, there are all manner of exceptions to this cut-and-dried summary of a case of natural selection: a female with a shorter ovipositor might push an egg deeper than one with a long tube; during one winter less depth of burial is needed than for another winter. We can never know all the ins and outs of even a simple example of the struggle for existence. But the principle

is truly set forth. Temperature and soil conditions can select unfavourable variations of crickets, and thus gradually alter their forms more surely than any human breeder could.

Nature works surely, and in the long run works exactly. But in any one season selection may be very irregular. Some of the best-fitted animals may die by accident, and some of the unfit may have the good fortune to survive. There is no precise standard of what is absolutely *most* fit. Nature, in general, destroys those animals that are *less well* fitted for the struggle. The fact is that natural selection is "survival of the fitter"—it is a comparative matter. It may happen, also, that some weaker animals, cut off from competition, can survive for a longer time than others that are stronger but that live in fiercer competition. All is relative. We can only say that in any set of conditions the animals that are more fit have a better chance to survive.

The impersonal forces of nature alter the dimensions of an animal in ways that are less direct than in the case of crickets. It was once found that the crabs on a beach near Plymouth were growing slightly narrower. Careful measurements in hundredths of inches showed unmistakably that a general progressive change was going on, that some force of nature was selecting out the broad crabs and killing them. So the puzzle was: "What change in the environment is putting broad crabs to death?" One shrewd observer guessed that the cause might be an increased amount of clay in the water, for it was known that the working of more land up the river had caused more clay to be washed to the ocean, and that the very fine particles of the clay kept the shore water somewhat muddy. An experiment in a laboratory proved that the guess was right; for if a lot of crabs were kept in a tank of slightly muddy water the broader ones died. No one knows the reason why the broad crabs cannot live; their mere breadth cannot be the cause; it happens

that the broad ones are constitutionally unable to resist muddy water.

Here was a demonstration that year after year the clay particles from the river were removing a certain variation among the crabs—just as certainly and just as accurately as the temperature of different regions selects certain unfit crickets. If a great deal of clay had come down the river some spring all the crabs might have perished at once. But since it increased gradually, it first selected only the very broad ones, next year those not quite so broad. Each year there was a weeding out of all crabs that varied toward broadness; and there was time for the variations toward narrowness to develop and survive, "leading to a change in the proportions of these crabs, which, if continued at anything like the same rate even for a century, would so alter the shape of these animals as to produce what would certainly be described as a new species. . . . There seems little doubt that we have here a means of seeing natural selection actually at work."

Natural selection is as impersonal as sea-water and climate; it has no design, no purpose; it moulds heredity as mechanically as waves shape the rocks. It cannot create a species any more than waves can create granite, but can only pound away at the variations that perpetually occur in every stream of germ-plasm. In the nutmeg tree, for example, there are constant variations; climate and competition pound away at the unfavourable ones, which are never allowed to propagate. If man interfered with the nuts, he might preserve variations of the rind that were slightly more pulpy, and by a long series of such selections, taking advantage of any sports in this direction, he might convert the bitter rind into sweet pulpy fruit—just as the bitter rind of an almond could be altered into a peach. Man could do this by design. The forces of nature select out from the rind every tendency to sweetness and pulpiness; any nut that has a slightly sweet

or pulpy cover is not so well protected and will have less chance to reproduce itself.

Natural selection has no power to help a plant by causing a favourable variation. If the crabs had not possessed in their germ-cells the apparatus for growing narrower, if the nutmeg had no apparatus for producing a tough and bitter rind, natural selection could not operate. Insects could often lay their eggs to better advantage, but no useful variation of instinct happens to arise, and the females continue to blunder.

Variation is not a matter of mere visible alterations; it occurs in all the fluids and organs and cells of every part of all bodies; chemical components vary, and nervous adjustments. A very important organ of earthworms, which normally is in two parts, may sometimes occur in three or four parts; an important duct may open anywhere from the tenth to the sixteenth segment. Some birds and giraffes lack a gall-bladder, and sheep have been found with three gall-bladders. Here is material—if it originated in chromosomes—for natural selection to work on. Such variability in every generation means that worms and giraffes and sheep can be adapted to new conditions of life, that if one sort of variation is rigorously removed another is ready to prosper and increase and predominate in heredity.

A peculiar and spectacular variation that seems to be rather common among larger animals is a big shift in the proportions of the jaws—the "bull-dog type" of face that sometimes appears in cattle and pigs. Fishermen occasionally find a "bull-dog cod"; this seems poorly adapted for life on the floor of the ocean, but it persists in appearing once in a while and might, if conditions changed, become the regular type. There used to be semi-wild cattle on the ranges of Argentina that had a bull-dog type of head—the lower jaw protruding, the upper lip receding, and the incisor teeth exposed. These are hardy enough ordinarily and are a favourite breed;

but in a dry year, when the grass is short, they cannot crop so close, and would starve if man did not feed them. All about them, in the last inch of grass which their short upper lip cannot get hold of, there are tons of good food, but they are powerless to pull it into their mouths. The bull-dog type seems to be continually seeking its chance in many parts of the animal kingdom, but is always removed by natural selection. It is an interesting example of the wealth of variation that selection has to work on.

Such a case shows that germ-cells are as ready to continue making one type as another. Professor Morgan found in his abnormal, unfit fruit-flies that "adaptive characters are inherited in exactly the same way as are those that are not adaptive." So variation is for ever furnishing the material of adaptation, and heredity is always prepared to preserve it; the result is determined by the way in which the struggle for existence destroys forms or allows them to develop.

Canaries were for untold centuries a green bird. For some reason the occasional yellow sports could not succeed—perhaps because they were more easily seen by their enemies. After canaries had been bred in captivity for two hundred years they were still green birds. But then a sport to yellow was fancied by one breeder, and this became fashionable. Nevertheless, after the green colour had been ruled out by artificial selection heredity could still be counted on to furnish occasional green birds. It acts the same way in nature. When rats or dogs or rabbits or cattle are turned out in new surroundings to run wild the operation of natural selection is always seen. "It has happened on two or three occasions that European rats have been accidentally imported by ships upon some of these islands, and even already it is observed that their descendants have undergone a slight change of appearance, so as to constitute them what naturalists call local varieties."[1] We cannot guess at the obscure

[1] G. J. Romanes, *Darwin and after Darwin.*

ways in which natural selection acts on such immigrants —why in the new surroundings a slight variation that used to be favourable and predominant is now unfavourable and perishes. But so it always is. "When an animal has to struggle under circumstances inconceivably complex," says Darwin, "modifications of the most varied nature in the internal organs as well as in the external characters, will be rigorously tested, will be preserved or rejected."

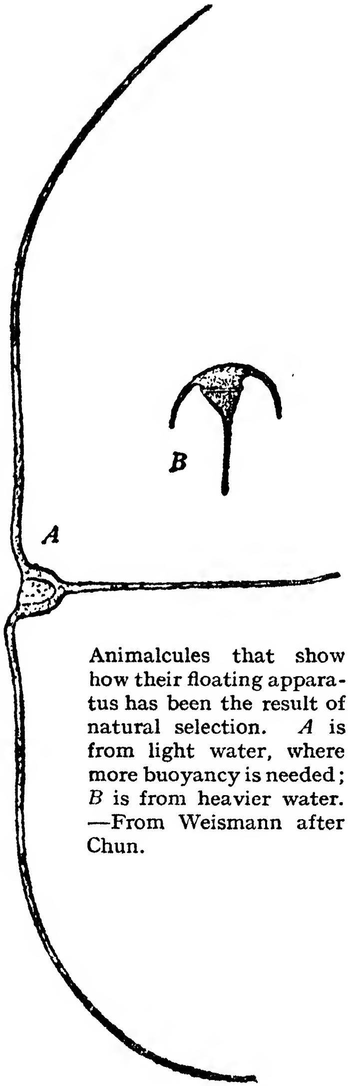
In Europe a certain species of lady-beetle shows many variations of colouring, but for some reason these are selected out much more rigorously in America, and the colour pattern remains very constant.[1] Another species has a much more constant pattern in the western states than in the eastern. A third species shows changeable stripes in the eastern states and constant ones in the western. For reasons quite beyond our ken natural selection bears harder on a variation in one region than in another.

These minute studies of spots on small insects may seem petty business, but there is as much meaning in those varying colours as in the prodigy of an ancon sheep. Colours may be matters of life and death to animals, and any differences in them are the result of severe and accurate selection in the competition for life. What is more, every spot of colour was provided for in the pattern that a chromosome inherited and then transmitted. Here we can see how nature sifts out some variations and permits others to reproduce, though we have no clue to the reason.

But sometimes we can understand the action of natural selection. One kind of animalcule,[2] living in all the oceans of the world, gives a beautiful exhibition, as clear as any chart, of how the changes in germ-cells are sorted out. It is shaped like an anchor. From its

[1] R. H. Johnson, *Carnegie Publication* 122: *Determinate Evolution n the Colour Pattern of the Lady-beetles.*

[2] A genus of the Peridineæ, *Ceratium.*



Animalcules that show how their floating apparatus has been the result of natural selection. *A* is from light water, where more buoyancy is needed; *B* is from heavier water. —From Weismann after Chun.

lumpish body branch the slender, tapering stem and two slender, flexible arms. These arms are floats to support the animal at the right depth in the water. It will need longer floats if the water is less buoyant, just as a person needs a larger life-preserver in a fresh-water lake than in the heavy water of the Dead Sea. Hence we could predict that if one of the animals is born with arms too short for light water or too long for heavy water, it will be floated at the wrong depth and will perish, leaving no descendants. Investigation shows that this is exactly what happens. In the Gulf of Guinea, where the water is light because of its warmth and its small amount of salt, this creature's horns have to be ten times as long as its body. But just in proportion as the water grows

colder and saltier, so that it is more buoyant, shorter horns are needed. In one of the ocean currents the same size of body is floated by horns only one-tenth as long as are needed in the Gulf of Guinea. Salt and temperature do not manufacture horns. But they do most accurately select out and destroy all those animalcules that vary in a slight degree from the proportions that are needed in any given part of the ocean.

The longer a naturalist studies the more he sees natural selection everywhere and always at work. He learns to decipher the stories of adaptation as if they were written in a book. But the language is a foreign one which he has to learn to translate. When he has become expert, the queer idioms of adaptation grow familiar and sensible, until at length he can make out a clear and consistent message of evolution.

4. *How Natural Selection "Makes" Adaptations*

I will give a few common and brief examples of how the nineteenth-century naturalists learned to read the record of nature and to find out how adaptations were "made." This knowledge has been so much extended in the twentieth century that science now constructs the histories of species almost as confidently as if it were telling of Rome and Thebes.

There is a species of nut-jay which ranges from the Alps to Siberia. In the Alps it has to get food by breaking up pine-cones, and there it has a thick bill that is well adapted for such hammering. But in Siberia it cannot secure food that way; it has to reach into cedar cones, where the seed lies deeper than in the pine; and in Siberia it has a bill adapted for reaching—longer, more slender, with the upper jaws protruding a tenth of an inch over the lower. The history is easy to read if one knows the language of chromosomes. When the species originated, those birds in a pine forest that varied toward

slender bills could not live through a hard winter when the competition for food was keen; and in a cedar forest those that varied toward stubby bills could not survive a hard season when there was not food enough for all. In this struggle with cones and cold the unfavourable variations were selected out; and as the centuries went by these two impersonal forces were the cause of adaptations.[1]

There is a genus of butterflies, widely distributed over the earth, that offers a puzzle in colours: in some species both males and females are brown; in others the males are bright blue, while the females are brown; in some species the males show only a trace of blue. This genus used to be as much a mystery as Aztec inscriptions; nobody could read its history in the blue and brown wings. But the record is easily deciphered when we use the key of sexual characters; the scent-scales and the blue colour are male variations—like the spurs and plumes of birds. Those species that have neither character must be the oldest, and those in which the males show a slight colour must be of more recent origin. If the males are bright blue and have well developed scent-scales they must be more recent still, for variations never go backward along the same track. Younger still must be any species in which some females show a trace of blue, for this sex-character begins in males and goes from them to the females. The spread of blue shows the comparative youth of a species. We should expect that as time went on a species would develop in which all the females would be a full bright blue. And this is the case. In the tropics, where selection seems to work faster, one species has already gone to that limit. It must be very young—as time goes for the biologist. The student of butterflies is as sure of this as a historian

[1] This and the two following examples are from Weismann's *The Evolution Theory.*

who states that Alexander the Great occupied Egypt before he invaded India.

All through the animal kingdom enemies have selected variations in the most remarkable ways. If a little bird is coloured like its surroundings, the hawks soaring far above are less likely to see it; it therefore has a better chance to survive. But if it is conspicuous, it is likely to perish and leave no descendants. It is for this reason that, as a rule, white birds cannot survive among green trees and that white pigeons are more preyed upon than coloured ones and that dark-coloured birds cannot survive in arctic snow; experiments prove that if insects and birds are put among foliage to which their colour is not adapted they are quickly killed off. And this has always been true in nature. If germ-cells of insects happen to vary in such a way that they make a colour pattern which is more conspicuous in the surrounding foliage, they doom the insect to death; if they happen to vary a little toward a concealing pattern, they make an insect more fit for the struggle, more likely to survive. As the centuries go by those unfavourable habits of chromosomes are continually being sifted out; every favourable tendency is more likely to be inherited. In this way the birds, by killing insects that have unfavourable variations, gradually bring about the most extraordinary alterations of the colours of insects, until the patterns of the wings and bodies imitate the appearance of the leaves or bark upon which they live.

If a certain fly succeeds better in having its eggs hatch because a variation has made it look a little bit more like the bees in whose cells it lays the eggs, its fortunate variation will have a chance to reappear in some of its offspring, and thus they will be more likely to prosper. Such a variation tends to continue and to increase. Those flies in the third generation that have more favourable bristles or shape of body will have success; and so the spurts of variation are slowly directed

in a course that may finally lead to the most incredible resemblances. If chromosomes shape a duckling that is somewhat better camouflaged than its fellows, it is more lilely to survive and continue a stream of germ-plasm that has possibilities of varying still more toward useful colours. If a non-poisonous snake happens to be born with colour spots that give it even the slightest resemblance to a venomous species, it has a somewhat better chance to survive and to set going a series of variations that approach more and more nearly to the venomous appearance. Its enemies are constantly allowing the favourable spots to survive, and thus in time may bring about a case of mimicry that seems too strange to be true. But the imitation is a fact in Brazil; the evidence is so clear that scholars are forced to accept it.

It is hard to believe that a bee's sting was gradually built up by a series of selections of "accidents," and the development of such an instrument as a hawk's eye is a process that makes the imagination blink. Certainly we should like to have someone discover an easier theory than natural selection.

But all the present signs are that natural selection has come to stay. It is approached in so many ways, it can explain so many conditions, it is so in accord with the plain facts, that it grows in force every year. It has shown two generations of naturalists how the plants and animals became what they are. It can sometimes be seen at work; and whenever we assume that it has been at work we secure a sensible result. The man who has used natural selection for many years does not feel that it is in the least weird. What staggers his imagination is to try to think how he could live without it.

One illustration among the caterpillars will show how the practical naturalist finds that the theory will lead him right. The caterpillar of the death's-head moth is coloured in such a way that it is conspicuous on potato plants in Europe; it has to protect itself by eating at

night and burying itself in the ground during the day. This appears to be a case where selection has not adapted an animal to its surroundings. But the caterpillar is not a native of Europe. In its original home, Africa, its colour is a most elaborate "imitation" of the leaves of the plant on which it feeds. There it stays out on the leaves all day long.

To tell all about adaptations in animals would be to describe the whole animal kingdom. To give a slight outline would require a book. (Wallace's *Natural Selection* is a readable one.) Here we can glance at only a few points of the panorama of adaptations. The most useful will be some examples of how often a long series of adaptations, graded from a crude beginning to a finished product, are spread before our eyes in the world about us.

If I take up a lobster's claw[1] and ask myself how it was developed by selecting chance variations, I am utterly at a loss. Yet a student of sea life has seen the series of steps. He can take out of the ocean specimens of a dozen different species and set them in a row on his table to show the following graded series: (1) a leg, the last joint of which can bend against the next joint and clasp an object there; (2) some roughening of the last joint, so that the object is held more securely; (3) a protruding of that next joint, till it forms a better surface for the last joint to work against; (4) an enlarging and curving of the last joint; (5–12) further steps of the same sort to a real claw. The student does not have to depend on a theory; for the principal steps, the ones that are hardest to believe, are before his eyes. In a similar way, and with no exercise of fancy, the student of anatomy can go a great deal farther, can trace back from the developed leg to a mere jointed ring of the body; he

[1] This and the three following examples of development are from the *Origin of Species*, and Huxley's *On the Study of Zoology*.

can look farther back, down the vista of development, seeing the complicated parts grow simpler, until the lobster looks almost like a jointed worm.

Does it sound fanciful? Huxley once said to an audience, after he had outlined this course of development, "I imagine I hear the question, How is all this to be tested?" He declared to them that there was a time when "endless dreams about the development of structure threatened to supplant science," and he had to prove to his classes that what he told them about the evolution of the lobster was not imagination. He began his proof by saying, "Our lobster was once an egg." He described the development of this, telling of "the rings that are first sketched out," "the bud-like prominences on them," "the growth of these into appendages"—in short, the living proof, in an embryo, of the anatomist's theory. "These," he said, "are wonderful truths—the more so because the zoologist finds them of universal application." Some description of them is given in Chapter XVI. They are the sort of confirmation that no biologist can resist to-day.

In the whole development of the lobster there is no sudden miracle, no alteration which does not come by slight changes that seem easy to account for. In all the elaborate machinery of legs and claws there is little that is really new, for most of it has been made by merely *altering the proportions.* In the case of animals it has been estimated that ninety-five per cent.[1] of all the evolution is nothing but the extension of some parts and the reducing of others. The continued altering of the proportions of the parts of an animal may result in a creature that appears utterly different. The same is true of the altering of parts of simple plants to produce the higher ones. It is the series of gradual changes of proportions that drive a botanist to rely on evolution.

[1] H. F. Osborn, *The Origin and Evolution of Life.*

He can in most parts of the vegetable kingdom arrange a set of plants, graded by slight differences from each other, that lead up to the same steps by which he had reasoned that natural selection might have developed the plant that he is studying. If he has asked himself how an iris came by its very peculiar apparatus of pistils and stamens, and if by his knowledge of how insects fertilise flowers he reasons out the probable steps of adaptation, he can gather a set of blossoms that will parallel his reasoning. You recall Darwin's description of the orchid that gave bees a ducking in order to get itself fertilised, and you are sceptical as to how any process of selection could build such an intelligent bath-tub; but from the seven thousand species of orchids a series could be arranged that would be almost like a motion-picture of the gradual development. When a botanist has compared for forty years, in many countries, the slight degrees of adaptation that fit the different species of orchids to slightly different insects, he believes in evolution as firmly as a traveller believes in railway trains. A savage cannot believe that steam will drive an engine, and he will argue the matter; but the civilised man buys a ticket, confident of being hauled to his destination. So the scientist no longer debates evolution; he uses it. He may have some wrong ideas about *how* it operates, but he knows that it is at work.

The basis of belief in evolution is the *graduated series* of forms. An adaptation does not stand by itself as an isolated marvel, but is in a series of rather similar adaptations, a series that carries a zoologist easily to his conclusion. Perhaps the ants come nearest to being unlike anything else in the world; it might seem that here at least we could not explain the peculiar arrangements by any process of selection of variations. Think of their three kinds—the queen, the male drones and the neuter workers. Yet a zoologist, familiar with a thousand kinds of variations of sex in all parts of the animal kingdom

could arrange a list of sex-adaptations that would represent the course of development in ants. There is nothing exceptional about these sex-groups. Nor is each sex-group made up of invariable creatures that are all of a kind. "The neuters of these British ants," says Darwin, "differ surprisingly from each other in size and in colour and in their eyes; yet the extreme forms can be linked together by individuals taken out of the same nest. . . . The difference between neuters of this African ant was the same as if we were to see a set of workmen building a house, of whom many were five feet four inches high and many sixteen feet high; the larger workmen had heads four instead of three times as big as those of the smaller men, and jaws nearly five times as big; the jaws differed wonderfully in shape and in the form and number of the teeth. . . . Yet these sizes *graduate insensibly into each other*." That is what an observer always finds—variations that graduate into each other. He can see a long course of changes, which stretches without a gap from one form to a very different form. Nature is always setting before him these exhibits of how variations have been selected and of how readily the development can be continued.

If I think of the delicate, almost intelligent tendrils of a climbing vine, I cannot imagine any graded series of plant apparatus from the stem of an oak to the clasping coil of a sweet-pea. I am sceptical and ignorant. But the botanist cannot think of tendrils except as graduated series of development from other parts of a plant. He knows that in one vine they have developed from branches, in another from leaf-stems, in another from leaves. He knows many kinds and degrees of tendrils. He has seen, in plants that have no tendrils and never climb, how the young stems move in their growth, tending to go round and round in a spiral. To him the tendril of any plant is just one example of the selection of favourable variations; he can think of it only as part of a graduated series of

such adaptations. If you removed this evolutionary conception from his knowledge of plant life you would paralyse his knowledge.

All students of nature would be staggering in the dark if it were not for that conception. By its light they can read the world of life as it is and can see far back through the geologic ages. In its beams they see the variations of a four-toed animal no bigger than a cat, which were selected for three million years, till three of its toes disappeared and its size increased tenfold—and it was domesticated as a horse. The searchlight of evolution shows up the fossil history of an animal in Egypt whose upper lip grew larger through the ages, and in which the other variations of shape of leg and size of body were selected, until the result was an elephant. When we first hear such wonder-stories we are sceptics, just as we were when we heard for the first time of X-rays or radio. Ignorance has to be sceptical. But when we are familiar with photographs of our own bones and receive a wireless message from our own family we forget the first shock of scepticism. It is so with these series of adaptations. Many a modern scientist spent some days of boyish incredulity; now the marvel has become a commonplace in his day's work, like the incredible telephone or the utterly impossible petrol engine.

Scepticism is removed only by familiarity. The sensible man will not accept mere logic, for he knows how often logic goes astray; nor can he accept the incredible because "they all say so." If any reader asks me how a bird's instinct for migrating was ever made by the gradual accumulation of variations in germ-cells, I give it up. So I should be at a loss if an Eskimo asked me how my voice could travel over a wire; for I don't know *how*. What I do know is that my voice is heard at the other end of a wire and that a bee's sting is the end of a series of variations. I know of some steps in the series: the first fossil insects were

very crude; there was a long course of development before anything like a bee appeared, and it had no sting; the females had a pointed organ for laying eggs. That is worth thinking about. In a hive of bees the big males have no sting, but only those neuters which are undeveloped females. Here is the hint which biologists followed and which showed that a sting is a "modified ovipositor." We know that throughout the plant and animal kingdoms there are series of all sorts of variations for producing poison—from the prick of a nettle to the astonishing feats of gall-wasps; a wasp is cousin to the bee, and it has developed a refined chemistry for the egg-laying process. So here is the same ever-repeated truth: a long graded series of stings and a long graded series of poisons. A zoologist can live and work by such knowledge; he can breathe if he has it, but he would stifle amid the nightmares of nature if he had no such help.

Even the stages in the development of an eye can be shown in a series of animals gathered under one show-case: (1) a mere spot sensitive to light, as in certain animalcules; (2) an eye-spot that is covered by translucent skin and that has a special nerve; (3) a more developed spot, in which can be seen above the nerve a transparent jelly-like mass that acts as a lens to bring more light to the nerve; (4) an apparatus almost as crude, but which has a hard transparent covering and some colouring-matter at the end of the nerve; the slight steps of increasing complexity can be continued in a long and gradual scale up to the complex eye of a squid, which is so similar in appearance to the eye of a vertebrate.

Amuse yourself by trying to guess how a rattle-snake ever got its rattle. Then read in a dictionary forty years old: "The rattle represents the extreme of development of the horn or spine in which the tail of many other serpents ends." If you read on you will catch a glimpse

of the character of this animal: "Rattlesnakes are sluggish and inoffensive reptiles." No one could guess from that fact why a horn developed into a rattle, unless he knew that a great many animals, of all sorts, are so constructed as to advertise their deadly or offensive equipment. When we know about "many other serpents," we can see the kind of variations that natural selection has worked with to build a rattle at the end of a serpent's tail.

It is the whole range in a graduated series, from slight beginning to intricate last stage, that obliges the scientist to accept evolution for a guide. He is not infatuated with the principle, has not the least affection for it, and would shake it off to-morrow if he could find anything better; but until there is a substitute, he will use it as a compass for exploring the jungle of adaptations.

Hundreds of keen students, noted ones and shrewd, have for sixty years been translating the history of life by the light of evolution. They have made some errors, have not agreed on some points, are still in the dark about others, and have quarrelled about many particulars. But by their combined labours they have made out a fairly complete account of the general course of life on the globe. As to the beginning they know nothing, and do not pretend to know anything. They can only suppose that some original simple form of life, something simpler than a single cell, varied; that cellular structure developed; that several cells made up a colony; that the work of the colony was divided among different groups of cells, some securing food, some distributing it, some keeping off enemies, and some reproducing; that such groups varied continually in the direction of specialising, and thus became adapted to live as parts and not as independent wholes; that the whole groups became bodies, with organs to see and smell and move and reproduce. Here were species large and distinct

enough to be preserved as fossils; from this point on a part of the record is accurately preserved in the rocks.

Sixty years ago this explanation was a theory; thirty years ago it was so plain a truth that all the conservative works of reference adopted it as a matter of course; to-day the schoolboy knows that every form of life is descended from an earlier and less complicated form.

5. *There is no "Blind Chance" in Natural Selection*

It is strange to think that the whole height and breadth of organic life was caused by variations in germ-cells. It is doubly strange if we speak of these variations as due to "chance." For the common meaning of "chance" is mere luck, mere happen-so, without any particular cause. If I throw a penny high in the air, making it twirl rapidly, there is no knowing whether the fall will be heads or tails. We say that there is an "even chance," and we never think of any cause for its falling either way up. If "chance variations" were of this head-or-tail sort, then all the intricate adaptations of animals would have been produced by a lot of luck.

If anybody says he believes that the world of life was made by luck his statement sounds foolish. It doesn't sound sensible to assert that all the staggering marvels of an eye were formed by "mere chance." A man might just as well say that the Suez Canal happened to be dug, or that a magneto pulled itself together one fine day by a set of accidents, So if the theory of natural selection were based on mere luck it would seem foolish even to a gambler.

In fact, the word "chance" has sounded foolish to some people who are a great deal more logical than gamblers. John Burroughs, for example, was a highly intellectual man, an author of charming books; and he, though he loved and admired Darwin, was much offended at the idea that all adaptations were made

by hit-or-miss. Other thoughtful men have felt that a doctrine of "blind chance" is very dreadful. And it would be dreadful. If Darwin had meant to teach such an idea he would have been wild and wrong-headed.

But we know that he was one of the calmest and most careful of thinkers. Burroughs considered that he had a "master mind." So it is inconceivable that he blundered in such an elementary way. How, then, did Burroughs misunderstand him? By not paying attention to Darwin's plain emphatic explanation of what is meant by "chance." Burroughs supposed that Darwin meant, as we do, unthinkingly, in common talk, *pure luck which has no cause.*

But Darwin used the word in an entirely different sense, and never dreamed that any critic would fail to take notice of his explanation. No critic ever would have overlooked it if he had known the meaning that is given in the next paragraph.

Darwin was using the language of science. The scientist knows that nothing can ever happen without a cause. He says that every toss of a coin is made by such an amount of power as will turn it over just so many times before it alights, and that there is no more luck about turning it over one hundred and seventy-three times than there is about turning it over once. But we *don't know* how many times the force will turn it over; we *don't know* the cause of the heads or tails. The scientist says that no drop of water on a stormy ocean, no atom in a chromosome, can possibly be altered in any way except as the result of the absolute law of cause and effect. Though we say in every-day life that "I met him by chance," or that "his death was accidental," the scientist knows that the exact circumstances of every moment were perfectly accounted for by the preceding circumstances. It is impossible to know the causes, but they were there. All such cases, *of which we cannot yet know the cause,* the scientist refers to as matters of

"chance." Savages and some bridge-players and superstitious people cannot understand this, and university students sometimes believe that things can happen without any cause; but the scientist knows that we can never escape from law, and that there always is a cause.

Burroughs accuses Darwin of not knowing this. He says, "Darwin everywhere uses the word *chance* as opposed to law, or the sequence of cause and effect." The accusation is utterly untrue. In the *Origin of Species* the word is clearly defined at the beginning of Chapter V.: "I have sometimes spoken as if variations were due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation." That is exactly his use of the word—to mean that *we know nothing of the causes.* He is everywhere careful to indicate that any variation must have a cause, using such expressions as "the dimly understood *laws* of variation . . . variability is governed by many *unknown laws* . . . all these *causes* of change . . . variations, from whatever *cause* proceeding . . . as we do not see the *cause,* we invent laws! [said ironically] . . . differences given by nature; I mean by 'nature' only the action of many natural *laws.*"

Darwin seldom uses the word *chance*—for fear of the heedless critics. Once he says, "Mere chance, as we may call it." He found it convenient and proper to use the short word *chance* as an acknowledgment of ignorance, instead of explaining himself at length every few pages.

In another book Darwin illustrates his meaning by the pieces of stone at the base of a cliff; we speak of their various shapes as "accidental" though we know that every least fracture was made in strict accordance with law. From these stones to the remotest nebula in the heavens every shape in the universe has been

produced by definite causes. Nothing happens without a cause. And it is so in plants and animals. The infinite variety of forms was produced by strictest law; for every item of structure in every individual there is a cause. When biology tries to trace the causes it can take a certain number of steps—back to chromosomes or genes. Farther it has not been able to go.

Science observes certain facts about the failure and survival of animals in their efforts to live, and it gives a name to those conditions. That name—"natural selection"—is not a power that works like a spirit or a man. It is not a creative force. It is a label that is put on a great body of knowledge, just as "the weather" is a convenient name for all those facts of temperature and water vapour and sun-spot electrons that cause sunny days and cyclones and snow drifts and fog and rain. The weather is a set of forces that we feel and see. Natural selection is a set of forces which determine that adapted plants and animals shall succeed in the struggle for existence.

6. *What Evolution cannot do*

Evolution cannot originate life. Children always inquire about first causes, expecting parents to tell them who made God. In much the same way we older people are prone to ask of evolution, "How did life begin?" And some scientists have speculated about the origin—whether the first cell travelled to us on a meteor, whether the first speck of protoplasm was made by a lucky aggregation of molecules in warm mud, etc. These are sheer guesses, scientific play. Nobody has the least knowledge of how life began. The evolution theory makes no pretence of explaining origins. "Biologists," says Woodruff, "are at the present time absolutely unable, and probably will be for all time unable, to obtain

empirical evidence on any of the crucial questions relating to the origin of life on the earth."[1]

The idea that science is trying to reach origins makes some people dread it. They have an uneasy fear that perhaps it will remove the mysteries of life, will strip it bare of sentiment, and will reduce poetry and religion to a skeleton of facts. Any such uneasiness is a quaint misconception. Science has no such expectation. The deeper it investigates the more it is involved in mystery; and it does not reach any explanation of the origin or nature of life. The true scientist is aware of the poverty of his little store of facts, for he knows much better than we how awesome and impenetrable are the ultimate secrets of the working of evolution. Huxley said that "in ultimate analysis everything is incomprehensible."

It does not cause progress. We all have a habit of thinking that evolution is an ascending scale of life, from a bottom somewhere in the slime up to a splendid horse or a noble dog. We have all our lives been accustomed to thinking of animals as "low" or "high" in the scale, and we naturally suppose that a development from bottom to top means moving onward and upward.

Mere science can detect only one case of what might be called progress—the advance from simpler forms to more complex ones. Even to this genêral course of evolution there are big exceptions: some species grow simpler in form after taking up the life of a parasite, and a great number of simple forms of life seem to have persisted through the whole of geologic times without progressing in complexity.

Otherwise science cannot assert anything about progress. People reason about it and form opinions, but they cannot agree on a definition of it. Science has not yet discovered any definition. Science simply

[1] *Evolution of the Earth*, p. 107.

tells us that the forms of life are constantly altering to adapt themselves to conditions, and it uses the words "better," "more fit," "improved." But it always refers to temporary adjustments in particular cases. It can never prove that any adaptation is "progressive," but only that it is "another one." If a simple animal is well adjusted to its conditions, it might be said to have "progressed" farther than a complex organism that is failing to adjust itself; but that is a very doubtful proposition. "Progress" is a matter of emotion, like "love" or "patriotism"; and it is much less definable, and much more a matter of prejudice. With such debatable sentiments science cannot deal. It puts the facts before us and leaves us free to thrash out our opinions. If a scientist wants ideas about the one increasing purpose that runs through the ages he turns to poetry and religion.

It does not cause perfection. If we look back through the history of life we find no examples of anything like perfection, or of any moving forward to it. The most admirable adaptation is only a temporary device, dependent on other temporary adjustments. When a reptile has so altered as to live in trees and to fly with feathered wings it may appear "improved," and we perhaps expect a continued improvement in beauty and intelligence. But thousands of species of birds have perished—one of the most numerous and successful and beautiful was snuffed out during our lifetime. Its powers of flight and reproduction were no nearer to perfection than the highly successful reptile from which it descended. Its new powers meant new enemies, new perils; and no future adaptation of other birds will be permanent. Every adaptation of every animal is a way of succeeding fairly well, only well enough to keep the species alive for some thousands or millions of years, till conditions change and fresh variations are selected.

Science tells us to use our best judgment and not

to fight about "progress toward perfection" until we are sure we know what we mean by those words.

7. *Natural Selection begins with Variations*

"Several writers," said Darwin in the last edition of his *Origin of Species*, "have misapprehended the term Natural Selection." At the close of this Part I. we should dwell upon his words. Darwin had defined his term with scrupulous care, and yet writers had misunderstood—not pupils in school nor business men nor hurrying editors, but professional critics of a scientific theory. No reader of this elementary chapter of a small book should be too confident that he will keep out of error.

For some reason even trained minds are likely to slip away from the one central and necessary fact. There seems to be some fatality in the central idea, for it always tends to slew round to one side and to hide itself. It played before the minds of men century after century and let them touch it, but it always slipped from their grasp. It played with Darwin, who groped for it and grabbed at it, and almost had it, and lost it. At length it grew over-confident. One day Darwin's mind made a lucky clutch and seized it firmly. He describes the affair thus in his *Autobiography*: "I can remember the very spot on the road, whilst I was in my carriage, when to my joy the solution occurred to me."

The trouble with all men up to that moment had been that they looked in the wrong direction. Darwin directed them to "modified offspring." An explanation of evolution must always begin with "modified," that is, stated in modern terms, with variations, that occur in germ-cells. We must look first at chromosomes.

The prime fact is that chromosomes are variable. The "chance" variations in them produce offspring that are not exactly like the parents. These variations are quickly sifted out and perish if they are unfavourable

for the struggle for existence. But if they make an animal more fit—even in the very slightest degree—they are less likely to pass through the sieve, and so may survive. When they survive, there is a slight change in the adjustment to life conditions. And when the change becomes great enough for us to see it is called an adaptation. That is the first—and the last—word in evolution.

Part II

THE EVIDENCES OF EVOLUTION

CHAPTER X

WHAT "EVIDENCES" ARE

An astronomer can prove absolutely to anyone trained in mathematics that the planet Venus revolves between the earth and the sun, but it is doubtful whether any biologist will ever be able to give any similar proof of the theory of evolution. The biologist is convinced by numerous probabilities, each of which is strong, and all of which combined he finds irresistible. It is impossible for him to see how all the lines of evidence could draw together so perfectly toward one conclusion that is false. He would not be fully persuaded by any one indication, and might not be by any two; he is completely convinced by seven kinds which, quite independently, point to one central theory. It is the purpose of Chapters XI. to XVII. to describe briefly these seven converging lines of evidence.

The nature of these probabilities may be illustrated from the study of history. Suppose that some sceptical reasoner should challenge the belief in the existence of King Alfred. If he had any skill and sense of humour, he could make a strong argument to show that Alfred is a mere "guess" of the historians; for the proofs that such a man actually wore a crown and built ships in Britain could be made to appear a flimsy thread—just a few old manuscripts, most of them written long after Alfred is said to have died. The ridicule could be easily made by any clownish essay writer. To prove that we have reliable knowledge of Alfred would be a long task; and when the proof had been carefully built up, it could

be laughed at once more as a string of "guesses." In like manner the history of the rocks may seem to an amateur a slight and dubious record, but the geologists who spend their lives with it are as sure of their knowledge as they are of the street in which they live.

Only the professional scholar can judge the evidences of chronicles or rocks. You and I would never give heed to a critic who tried to demolish history—*so long as all historians agree against him.* You and I pay no attention to a critic who rails against the germ theory of disease —so long as all bacteriologists agree against him. We do not believe in perpetual motion or the flatness of the earth or the effect of the moon on crops—so long as the whole body of specialists in the subject are agreed against such beliefs.

What is true of all lines of science holds for the Evolution Theory. If we could find that many reputable zoologists or botanists doubted the theory, we might suspend judgment or might disbelieve. If practically the whole body of scholars is united, we accept what they say. We must do so if we are normal and rational. And there is such unanimity among naturalists and laboratory workers to-day. To be sure, they have variant views as to just *how* the process has gone on; but they are all at one in believing that, as a matter of fact, by whatever mode, evolution has operated and that every present form of life developed from some previous and different form.

Hence Chapters XI. to XVII. will be misunderstood if they are read as arguments. They are descriptions of the way the whole body of scientists look at nature. And the chapters will be misunderstood if they are read as attempts to prove anything, for proofs are far beyond my amateur powers or ambition. I prove nothing. I describe a great body of unanimous scientific conviction.

CHAPTER XI

THE EVIDENCE FROM THE ROCKS

IMAGINE yourself amid a series of gently-rolling hills covered with rich grass, where not a rock is to be seen in any direction for a hundred miles. Here are two knolls different from anything in the region, composed entirely of gravel and rounded stones, some a foot in diameter. You are a thousand miles from the ocean, and yet in one of these small boulders is a perfect sea-shell, such as was never made in fresh water. How did the stones and the shell reach this position? This is a trifling example of the unanswerable questions that curious minds had always been putting when they observed the surface of the earth before 1700. In the Rocky Mountains there are beds of coral; there are vast beds of lava where no volcano is in sight; there are sea-shells near the top of the Alps; embedded in the rocks, hundreds of feet below the surface, there are impressions of leaves that are as precise and complete as if they had been made last week in the finest plaster of Paris; there are tracks of all sorts of animals, as legible as last night's hoof-prints to a hunter; there are skeletons, preserved with the minutest accuracy, of animals unlike anything that lives to-day. The rocks that bear these evidences of past life are of all kinds—some lying in level layers, some tilted, some in broken arches, some partially fused by heat. Inquisitive minds had wondered for twenty-five centuries whether these old manuscripts of nature could ever be deciphered—written as they are in an unknown language on broken and jumbled leaves of rock.

The ancient Greeks reasoned quite naturally: "If there are sea-shells in the mountains, then the sea must at one time have been where the mountains now are." That was a very sensible supposition. It would have been followed up and proved bit by bit long before 1700 if the theologians had not been afraid that every such effort at explanation was an attack on the Bible. It was dangerous to teach that the earth was round, because the Bible said it was flat; it was impious to believe that the earth moved, because the Bible said it stood fast; it was blasphemy to guess that the hills and the ocean had changed places in the course of ages, because the Bible declared that the hills were everlasting and that bounds had been set for the ocean; to reason about the great age of mountains was atheism, because the Bible taught that the world was less than six thousand years old. Nearly all the devout people in Christendom honestly feared that any investigation of the earth's surface was perilous to the spiritual welfare of the human race. If Noah's flood would serve to explain the rocks, well and good; but any reasoning about another flood more than six thousand years ago was an attack upon religion.

All this is hard for us to realise in our day; and yet we still hear echoes of this dread of science. Some old-fashioned people are still afraid that the evidence from the rocks may damage the Bible. It is comical, though it is disheartening, to see that the human mind could ever have had faith in a Bible about which it was so timid, or could ever have been so superstitious as to think that the sacred Testaments were a volume of science. The great majority of the men who laid the foundations of geology were believers in the spiritual truths of the Bible and the real defenders of it; they insisted that it should not be desecrated by being dragged into the scientific arena, but that it should be elevated above and beyond science. It is still necessary to state this fact in every popular explanation of the record of

the rocks, though it has long been a truism and will probably not have to be rehearsed many years more.

Under this fear of seeming to dispute the Bible every investigator laboured in the eighteenth century. I will give only one illustration of how they were hampered, and then sketch briefly the history of the reading of the records in the rocks.

I once saw some tracks in the surface of a newly-laid cement road. Any man in his senses could have known that they were not made by an elephant or an ostrich or a lizard; even an ignorant fellow like me could know to a certainty that they were not formed by any animal with a hoof, nor by a rabbit, nor a squirrel, nor by a cat, nor by any dog less than a foot long. A keen trapper would have described, beyond any shadow of doubt, just what kind of dog made the tracks. If, now, I could have covered those few square feet of road, so that no sunshine or moisture of frost or chemical could disfigure the tracks, and if I could thus have preserved them completely for a year, another trapper could have known exactly what the first one did about the cause of the tracks; and ten years later, and fifty, and a hundred it would have been just as certain how the tracks were made. After a thousand years perhaps that kind of dog would be extinct, but a man in that age would recognise that the tracks had been made by an animal nearly like some variety that he knew. After ten thousand years the record would be unmistakable, and after a hundred thousand, and after a million; those half-dozen footprints would be evidence that in some minute of bygone ages some animal had set its feet in some soft substance that hardened and preserved the outline of its tracks. Even more unmistakable are the shells and skeletons that have been preserved by nature in a similar way. Yet the men who found fossils in the eighteenth century were asked to believe that the shells and bones were not real, but were "sports of nature," tricky likenesses—perhaps placed

there by the devil to lure men away from religion. If any Oxford professor had taught in 1750 that fossils were ancient remnants of real life he would have been regarded as a foe of religion.

But by that time the collectors of Europe had piled up and classified such stores of fossils that it became impossible for them to believe that the specimens were sports of nature. They had every appearance of being just as real as a feather or a skeleton found in the woods. Here and there through the centuries observant men had dared to speak of fossils as proofs that the ocean had been where mountains now are; for example, the great artist and scientist da Vinci wrote in his note-books about 1500 a lucid account of fossils. Contributions of this sort continued all over Europe throughout the eighteenth century, so that by 1800 the world had pretty generally accepted the fact that fossils were made more than six thousand years ago and were not deposited by Noah's flood.

All through the eighteenth century there was also in all countries a diligent study of the rocks themselves. It began to be clear, as workers from different fields compared notes and revealed one another's errors, that there had been a history of the earth's surface, that rocks varied in age, and that, in a general way, the youngest were on top. Many speculations were put forward as to how rocks were made, how they could be heaved thousands of feet above the sea, and what epochs of rock-making could be made out from the jumble of evidences. By 1775 the generally accepted theory was that the whole earth must once have been covered by the ocean, that the different sets of rocks were "deposited" by the ocean (somewhat as salt is when brine evaporates), and that three principal classes could be distinguished: the "primary" or oldest, which showed signs of having been fused by heat; the "secondary," or level strata on top of these; the "tertiary," or loose sand and soil. It was taken for

granted—as most people still suppose—that by studying the rocks men could find out which kind were early and which kind were late. It was, for example, assumed that lava was more recent even than the "tertiary" gravel, because men had seen it poured out on top of the soil.

All such efforts to construct a history of the earth's crust would have come to nothing. Lava flows have been found underneath the folded "primary" rocks; level "secondary" strata have been found under the "primary." There is proof that in one place limestone is more ancient than sandstone, and that in another place sandstone is more ancient than limestone. We now know that different sorts of rocks have been made at many periods of the earth's changes. No history of them, as rocks, could ever have been discovered.

The clue to the history proved to be the fossils embedded in the rocks. More than two centuries ago several Italian scholars published explanations of this general idea. They argued that rocks were probably formed in the ocean by the depositing of mud brought by rivers; that successive layers of this clay or sand or gravel were hardened into successive strata of rock; that certain kinds of animals were living when each stratum was formed and that these were preserved in their respective layers; and that therefore, whenever you found similar fossils in two sets of rocks at different parts of the earth, you had rocks of about the same age. We must sympathise with the men of that time who considered this theory fanciful. It had to stand the hardest kind of attacks for a hundred and fifty years, and it would not have survived if it had ever once been at fault. It has never failed to stand the test. Every decade has brought fresh evidence that it is the only key to the hieroglyphics of geology.

Late in the eighteenth century the head of a French monastery occupied himself with the study of the shells

in some limestone cliffs near the Rhone River, just as an Austrian monk in the next century studied his peas with scientific accuracy; and both became contributors to the Evolution Theory. The French abbot found five distinct sets of shells in the successive layers of limestone, and in the lowest layer were no shells of species that then lived in the world; from here to the top the shells grew increasingly to resemble modern types.

In 1815 an English surveyor, William Smith, who had for many years systematically observed fossils over large areas of England, published the maps in which he had classified the rocks according to the ancient plants and animals embedded in them. So thoroughly and shrewdly did he do his work that no serious flaw was ever found in it, and it became the starting-point of all true histories of rock that have been made since his day. In proportion as more and more old species are discovered and as wider and wider areas of land are explored, the truth of the fossil history becomes more evident. The more it is put to the test the stronger it grows. A modern geologist could no more expect it to be overturned than you and I can distrust our theory that winter will come again after next summer. Our faith in the coming seasons may be merely a theory, but we have confidence in it.

Throughout the nineteenth century the classifiers of fossils in Europe increased in numbers and knowledge and skill. Many wrong conjectures were made, many errors of observation; but the rivalry of science was always grinding down the mistakes and preserving the facts. Some wild theories were advanced by men who could not accept the crude ideas of evolution current before Darwin's time. One brilliant Frenchman, for example, inferred that at many times in the earth's history there had been a complete destruction of all plants and animals, and that each time a new and more advanced series sprang suddenly and miraculously into existence.

His guesses were disproved. From all sides, from students of all sorts of fossils in the old world and the new, came an increasing mass of evidence that there had been only one series of life and that it had developed continuously. There was increasing evidence that no great breaks or "cataclysms" had ever occurred in the earth's history. And as the outline of the history took clearer shape, it was seen to stretch farther and farther back into remote times. In 1778, when Buffon estimated that all life had existed about fifteen thousand years, he was considered extravagant; but fifty years later a hundred times as many years would have been thought a very low limit.

Though the knowledge of fossils continued to grow in fulness, it could not be assorted into any orderly arrangement, because scientists did not know what the succession of types of fossils meant. There were the shells and bones, as plain as any sign-board, but they were in cipher code. The greatest of the early scholars, Cuvier, published a vast amount of information between 1800 and 1830: he saw that elephants unlike any now living had once roamed in jungles where Paris stands; he saw the hippopotami and rhinoceroses and crocodiles that used to walk in France; he studied countless fishes and birds and serpents that no longer live. But what of it? How could these signs in the tiers of rock be decoded? Other men found, in widely-separated places, very precise arrangements of coiled shells; they were graded from the plain types at the bottom, through fluted and ornamented types, to a less ornamented type, and finally to a plain but noticeably different type at the top. In England and Italy and Germany were the same messages. They stared naturalists in the face, grouped as accurately as if they had been so many sizes of gravel-stones run through successive sieves; and nobody knew the meaning of this arrangement.

Yet even Cuvier agreed that one fact was obvious:

"there has been an upward development in the animal forms inhabiting the globe." No evidence ever appeared on the other side. As new series of fossil plants and animals were reported from America and Russia and India they always showed the same kind of arrangement; from the forms in the lowest stratum there was always development of some sort toward the forms in the highest stratum. No one discovered any arrangement of the opposite kind, or even of a somewhat different order.

By 1840 there had been reports from many parts of South America, from Australia, and from parts of Africa; the Geological Society of London and the Geological Survey of New York had been established. Everywhere men were scrutinising the rocks and fossils, recording what they saw in their part of the world, reading of what other men had seen in their countries. Murchison had gone below the coal beds in Wales and had found there the same kind of evidence that had been found above—that is, distinct layers of rock, each of which bore its own special assortment of fossils. He named these newly-discovered formations after the ancient inhabitants of Wales, the "Silurian," and confidently predicted that whenever the Americans could get a glimpse of rocks lower than their coal beds they would find there the same Silurian fossils, in the same order. And his prophecy had been fulfilled. In another part of Wales the Reverend Adam Sedgwick, an adept in unravelling rock mysteries, discovered a still older formation, with its distinguishing kinds of fossils; and this he named, after the ancient Wales, "Cambrian."

By 1850 dozens more of inquisitive geologists had learned so many more details of these ancient records that they could tell the difference between the earlier and the later layers of each group. So intimate became their knowledge of the different shells in the layers that if they had received from another part of the world a

certain sort of hinge on a shell of a certain size they would have known instantly whether it was of the Cambrian or the Silurian age; they could have told what other shells would be found alongside it, that certain other shells might be above this layer, *but could not be below it.*

Diagram, from Goodrich's *Living Organisms*, to illustrate the growth and death of species. The extinct ancestors in the fossil record are shown by dotted lines; species still living are shown in black.

No exception was ever found to this *order* of the fossils. Of course, there were all manner of complications and apparent discrepancies. Many kinds of animal and plant remains were found almost unchanged through many ages of rocks, so that they would not serve as indexes

to periods. There had to be wide study to learn what shells were indexes, and what the combinations of fossils signified. But in the main the fossil clues were found to be invariable and unfailing. The coiled "ammonite" shells became an alphabet of the earth's history, as unmistakable as if they were the letters M E S O Z O I C. In each decade since 1850 the knowledge has broadened and deepened, and grown in detail. If any single exception to the *order* of the fossil record had ever appeared, it would have blighted the whole science of geology—just as surely as the proof that there was once a czar of England would upset all our school histories. And fame has always awaited the geologist who could prove such an upset of the fossil record. But no man has been able to discover the exception. A geologist no more questions the story of the rocks than a boy who reads about yesterday's cricket match thinks the account is a myth.

Yet the geologists of 1859 were in the dark. By their flash-lights here and there they saw the unmistakable record; they pieced it together; they knew it as surely as they knew that they had eyes, but they knew it as a patchwork of incomprehensible fragments. The greatest of them all during a whole generation, Sir Charles Lyell, had no faith that there was any general progression of forms from the earliest times to the latest. His clear-headed judgment on all the facts that men had piled up was simply this: "We have not proved any progression of forms, from simple ones to complicated ones, through succeeding ages. We may yet discover the bones of a mastodon among the Cambrian shells."

Imagine what the Evolution Theory would have meant to you if you had been Sir Charles Lyell in 1859. "If Darwin is right," you would have said, "then his idea is like the glint of sunshine to a person who has been lost in the mazes of a cavern; if I follow his theory I shall be in the daylight henceforth. But if it is wrong,

it will be only the flicker of a candle in the hands of another man as lost as I am. Is Darwin right or wrong ?" That was the question that Lyell faced when, early in September, he unwrapped a parcel of some of the page proofs of the *Origin of Species* that had been sent by a London publisher. And imagine how you would have felt if you had been Darwin. After twenty-five years of constant labour and thought you have put your conclusions into the thrashing-machine. Are they wheat or chaff ? Will this greatest student of rocks and fossils accept my theory ? He is sixty-two years old : can he, at such an age, alter his whole view of the nature of life ?

"Do not be in a hurry in committing yourself," wrote Darwin to Lyell on September 2nd. "Remember that your verdict will probably have more influence than my book at present ; in the future I cannot doubt about the admittance of my views, and our posterity will marvel about the current belief." On the 20th he wrote again : "As I regard your verdict as far more important than that of any other dozen men, I am naturally very anxious about it." On October 15th he wrote to Hooker, the foremost botanist of England : "Lyell seems staggered by the lengths to which I go. . . . I entertain hopes that he will be converted, or perverted, as he calls it." On October 23rd, again to Hooker : "I had not inferred from Lyell's letters that he had come so much round. I remember thinking, about a year ago, that if ever I lived to see Lyell, yourself, and Huxley come round, I should feel that the subject is safe."

He had only a month to wait. Then came a note from Hooker which spoke of "your glorious book" which will be "very successful" and of how "Lyell is perfectly enchanted and is gloating over it." Lyell had already determined to admit the new theory to a revision of his *Geology*, and Darwin wrote to him : "To have maintained, in the position of a master, one side

of a question for thirty years, and then deliberately give it up, is a fact to which the records of science offer no parallel. I rejoice profoundly." Huxley wrote a favourable review and girded on the whole armour of his intellect to fight the good fight for evolution—or, as he put it on November 23rd, "I am sharpening up my beak and claws."

The whole meaning of the Evolution Theory to geology was thus summarised by a correspondent who wrote on the same day as Hooker: "How could Sir Charles Lyell, for thirty years, think on the subject of species *and their succession*, and yet constantly look down the wrong road!" Ever since 1860 geologists have been able to look down the right road. Read any text-book or encyclopædia article, and you will find testimony similar to this from the *Britannica*: "*The Origin of Species* produced an extraordinary revolution in geological opinion. The older schools of thought rapidly died out, and evolution became the recognised creed of geologists all over the world." In the light of the knowledge of evolution they have read a record of vast eras, a record which is all consistent, intelligible, indisputable. They could no more continue their researches without evolution than an historian could read if you took away his theory that lines of print begin at the left-hand side of the page. Hundreds of geologists are mapping rocks in all quarters of the globe. If they assume that all species of animals developed from previous species, they can make sense of the fossil record; if they should assume any other explanation, all geology would become a heap of meaningless curiosities.

No achievement of the human mind is more creditable than the building up of a connected narrative of the changes in the earth's crust. I offer a brief sketch of the result as an example of what the Evolution Theory produced when it was applied to this stupendous riddle and was found to be an unfailing guide. The first four

paragraphs have nothing to do with evolution and do not tell of a proved theory, but I include them in order to furnish a beginning of the story. It is based on *The Origin of the Earth*, by Professor T. C. Chamberlin.

A thousand million years ago or more, as one of the stars, our sun, was soaring along calmly another star came near. This meeting was quite in the ordinary course of things, for by the law of chances there must be now and then such encounters in the wide spaces of the heavens. It would appear that the star was larger than our sun and that its course happened to swing it very near the sun, though not producing a collision, and then to speed it away. Perhaps the meeting was only for a few days. The bulk of the star almost disrupted the sun, for its attraction was so great that the matter of the sun began to stream out toward it; and if it had come a little nearer it would have drawn the whole sun to itself. So adjusted did its course happen to be that during its approach it caused four bolts of sun-stuff to shoot forth, four more as it receded, and then sped away without doing more damage. (Such results are not an astronomer's dream; cold figures show that just these effects would be produced by a meeting of a kind very likely to occur.)

In such a sudden and spectacular way was the sun set upon and almost annihilated. Yet it had not been much diminished—no more than if you should draw off from a molten mass the size of a cricket ball enough material to make a small marble. The wreckage of the encounter was strewn about the sun in eight irregular bunches of molten minerals and gases, which rapidly cooled, spread out as they were in a temperature of four hundred and fifty degrees below zero. They had darted toward the star, bending after it as it raced away, but it had been too fast for them. So they were left within the range of the sun's attraction, yet unable to return to their warm home. There was nothing they could do

but continue to whirl in orbits around the sun. And there they have whirled ever since—eight planets, of which the third from the sun is our earth.

Each of these shapeless baby planets began to set itself in order. Its core rounded into a globe, to which the outlying fragments were attracted. As it went along its orbit it was continually drawing to itself the wreckage that lay there. As the centuries went by it continued to mop up its path, to gather the debris to itself, and so to increase in size. Countless tiny planets, the "planetesimals," pursuing their private courses around the sun, were daily drawn into the major planets.

That is the picture that the "Planetesimal Hypothesis" offers us of the origin of the earth. It is a conjecture so carefully calculated that it seems highly probable. According to this theory there was a period early in the earth's infancy when it was not half so large as now, cooled from its original heat, already surrounded by some air, and having on its surface the beginnings of an ocean. It grew gradually and uniformly, as cool at the surface as it is now, by picking up the bits of sun-stuff that it encountered. Since that earliest and briefest period of infancy it has never been molten, never even hot on the surface, never the scene of violent changes, never more disturbed by volcanos and earthquakes than it is at present. The history of our earth has been a placid one.

"Gradually, calmly, uniformly" is what the history of the rocks is for ever repeating to us. Most of us have been familiar with the contrary idea. "There were violent upheavals here once," travellers often remark as they look at the Alps; they think of the past as a violent volcanic age, which was in contrast to our slow and peaceful era. We are familiar with the description of the earth as a fiery mass that cooled enough for a crust to form, though it was still molten inside, that finally cooled enough after an age of frightful disorder to allow coal to form, that continued to cool and to thin

its atmosphere until some animals could live on it, that cooled to an Ice Age, that will grow colder still, and that will at length freeze into a dead mass like the moon. Recent geology knows of no such process. Geology tells us that as it was in the beginning it is now and, so far as can be foreseen, ever shall be. No making of mountains in the past was ever much more spectacular than what is going on now right before our eyes. There have been Ice Ages as far back as any record can be read in the rocks. Where the oceans and continents are now there they have always been. The land masses have come and gone and come again, but always in the same general locations. Since its romantic beginning the earth has had a quiet history, almost monotonous.

The modern geologist pictures the earth as made of a dense core, rich in heavy metals, kept hot by the work of its own gravity and by chemical action, and covered with a crust of lighter rock some fifty miles thick. Some form of adjustment is always taking place within its crust—not that it is "wrinkling like the skin of a drying apple," but that parts of it are contracting and expanding as they adjust themselves to the shifting loads on the surface. Some heaving appears to lift up masses of stratified rock—very gradually, through long ages—on certain fixed lines of adjustment in the crust, and so to make mountain ranges. Then may come a compression which slides rocks for fifty or even a hundred miles from their first location, and tilts them as we see them in Westmorland. Recently geologists have learned that the material under a mountain chain is lighter than the material which underlies the regions on either side of the chain: the mountains seem to be counterpoised by denser portions of crust. In the beginning there were certain lines of adjustment — about where the greatest mountain chains now are — and there the mountains have usually been made. There were certain regions of depression—and there the deep oceans have always

been. The changes in the earth's surface have been a routine, a slow pulsing in certain regions.

Though the alterations seem large to us, they are slight compared with the total bulk of the earth. The top of the highest mountain is only six miles above sea level, a height which would be represented on a twelve-inch globe by no more than the thickness of a sheet of note paper.

As soon as a mountain range begins to rise it is attacked by the water—worn down by friction, chipped by ice, decomposed chemically. Though it rises ever so high and is ever so hard, though the action of water seems ever so slight, the water will conquer in the end; for water has as many millions of years as it needs to complete its destructive work. Slowly it carries away the pulverised rock, carries it as silt to the sea, and deposits it. As the thousands of years pass the top of the mountain is being laid down in the bottom of the ocean. There it is subject to great pressure from later deposits and to a cementing process. It is converted back into rock. Layer is formed upon layer. Thus an increasing burden is laid upon the shifty foundation of semi-fluid rock several miles below. Some time the strain will become too great to be borne, and then this new-made rocky bottom of the sea will be slowly crumpled and lifted, perhaps only a fraction of an inch a year, into a new mountain chain—to be again worn down, and again raised up.

Suppose that five hundred million years is a correct estimate[1] of the time since the first animal left a record

[1] Barrell's estimate, on a uranium basis, of the time since lower Cambrian is seven hundred million years, and Schuchert thinks "this is excessive by fifty per cent." The figures will seem excessive to most readers, because they are five times as great as those given in most recent books of reference; if they are too high, they will be the first estimate that ever erred in that way. See the 1922 *Britannica*, article *Palæontology*. The data for the sketch of the configurations of North America since Cambrian time are in Grabau's *Textbook of Geology*, Part II.

of itself in the rocks. Suppose that an angel had been commissioned to take a photograph of the North American continent, as it appeared at that time, from an altitude of several thousand miles, where a lens could command a view of the whole expanse. Suppose that every five thousand years thereafter the angel had taken another view of the same part of the earth from the same point. If the one hundred thousand negatives thus far taken could be put together in a single film, they could be shown on a screen in an hour. Watching such a picture would be heaven for a geologist. What would he see?

Imagine that a map of North America is traced in dotted lines on the screen, so that as we see the views of the ancient land masses we can tell where they were. Understand that the reel which we are to see begins when half of the rock-forming history of the earth had already passed. Of all that previous history of the continual heaving up and wearing down of land we can have small knowledge. But we do know that before our motion picture began thirty-two miles of sedimentary rock had been laid down in the ocean and raised above it, and that during the time of the picture only twenty-one miles of rock were made.

As a prelude to the main reel comes a one-minute picture which gives two glimpses of the era before the Cambrian, and indicates that we are plunging into the middle of the total history. It is a close-up of the Great Lakes region. A sheet of ice stretches across Canada, its ragged southern edge quivering back and forth; after ten seconds we can see that it is retreating, as the tide goes out with a series of advances that are farther and farther down the beach. The ice disappears to the north. There is a heaving up of land. Then near where Lake Superior now is a volcano pours out smoke; another appears to the north of Lake Huron; great sheets of lava, hundreds of feet thick, cover wide areas. In them,

if we could but see, are the copper and silver that are now being mined in those regions.

The picture closes, and there is an interval. Then the main reel begins with some blocks of land that we should never recognise as the present continent if the dotted lines of the map did not guide us. There are three of them: the largest stretches from north of the Hudson Bay region, tapering to a point in Southern Mexico; the second is at the left, a block corresponding to Alaska and stretching south-east where the Canadian Rockies now are; at the bottom is the third block, where the West Indies now are, stretching in a slender north-easterly neck across to England. Long arms of the sea separate the two smaller land masses from the large continental one.

You watch the lower end of the great central continent slowly disappear, and the channels on either side of it widen slightly; the sea encroaches[1] somewhat on all the land for two minutes. Then for two minutes you observe that the sea is retreating and the land extending. During the following two minutes the changes are greater, for the whole southern third of the central continent is eaten away, and the other two blocks alter their shapes, becoming somewhat smaller in area. You do not find this entertaining. In seven minutes of the monotony you do not see as much change as a motion-picture ought to show in three seconds. You shift in your seat and wonder whether anything worth while is going to happen during the next seven minutes. The learned lecturer tells you that you have now seen the whole of the great Cambrian period and are well into the still greater Ordovician. You are not thrilled.

Still there is more doing on the screen. You see the central continent creep farther and farther south,

[1] So it appears on the screen and so the geologists speak of it. What actually happened, of course, was that the land sank.

widening as it goes, filling the arms of the ocean on the east and west, taking on an almost familiar appearance: you can see a Gulf of California, a San Francisco Bay, a Puget Sound, and a Mississippi River. Now the ocean begins to eat the land away, cutting a passage from the West Indies to the Arctic Ocean. The continent becomes a set of islands. So for a minute it remains. Then the land begins to grow, until a fairly respectable continent emerges, stretching unbroken from Northern Alaska to a tapering point in Southern Mexico. "The close of the Ordovician," the lecturer announces; "now note how the sea begins to wear down the continent and carve a north-and-south channel through it at the opening of the Silurian. The Silurian will last four minutes."

As an entertainment this sort of display on a screen would not draw crowded houses. Yet anyone with imagination has spent an extraordinary quarter of an hour, watching the rocks come and go with the slow lapse of millions upon millions of years. Every second of this picture represents one hundred and forty thousand years —ten times as long as the whole recorded history of man. A minute of these motions on the screen is longer than the mind can conceive—more than eight million years. Our quarter of an hour has meant fifteen times those eight million years, and yet that whole inconceivable extent of periods is but one chapter in the whole volume of the ages of the world.

We have seen on the screen nothing but the coming and going of land. What about life? When the reel opened life was already far advanced; there were beautiful scallop shells and jelly-fish and complicated crab-like animals. For aught we know these forms had been developing from simple one-celled animals during five hundred million years. In the quarter of the motion-picture that we have seen the corals developed, and the chambered nautilus, and a kind of fish. So much advance to show in one hundred and thirty million years!

Somehow, when we realise what this picture means, the remaining minutes of Silurian time will not utterly bore us. It represents twenty-five million years, during which the ocean three times reduces the size of the continent, and three times is slowly driven back by the rivers that pile sediment along the shore. There is a fascination in seeing this portion of the earth's crust pulsing back and forth, never entirely consumed in the waters of ocean, always returning to that shape that tapers off at the south in the familiar Mexican outline, always showing some sort of Alaskan and Canadian and West Indian land, always showing a tendency to gulfs where gulfs are now. And there should be wonder in our hearts as we recall that this history was never revealed to geologists by an angel. No, they had to pack burros and wield hammers and draw maps and study specimens and compare notes and exhibit each other's mistakes for a century before they could piece together the fragments that we are seeing by the grace of heaven. "If in this shale there is such a species of fish, and if this sandstone underneath it is of so coarse a texture, then"—by comparing thousands of such inferences they slowly built up the knowledge of where the ocean was at different periods. Fishes are not adapted to desert life, and ferns never grew in the sea; each fossil of such an adaptation as a fish or a fern shows what the environment must have been for that form of life at that time. There is no more mystery in reading the geological record than there is in reasoning that an old swallow's nest was made by a swallow. All that is required is infinite care and patience, driven by curiosity.

The records of the Silurian and of the Devonian that occupies the next four minutes show only one marked advance in organic life: certain fishes developed lungs, and so could live on the land. Plants also adapted themselves for living on land. At the times when the ocean was driven back there were likely to be certain bays

that were filled across the mouth; the water-dwelling plants and animals that were thus cut off from the ocean would perish as the water grew brackish and finally evaporated. But if any organism varied in such a way that water became less and less necessary to it, and if these variations were inherited and increased, that species could in time become adapted to live altogether on land. It would survive, while all the others would become extinct. Such development came about some time during the last two periods that we have seen on the screen. It was momentous. Life then escaped from the sea and began its career on land.

Now for eleven minutes you may watch the sea encroach from the north until it almost cuts the continent in two, and then retreat again. A close-up of this new land left by the retreating sea shows that it is covered with a strange forest, composed of forms like our modern ferns and horse-tails and ground pine, but magnified to large trees. It is a riotous growth of the plants that have learned to live on land and that have waxed gigantic in the rich, new, low, swampy soil. As the trees die the trunks and leaves form a kind of peat-bog that is transformed and compressed into coal. Insects swarm in the forest—some early elementary kinds of beetles, cockroaches, and especially dragon-flies, some of them thirty inches long. There is a reptile that reaches a length of eight feet.

The semi-tropical growth fades away. The land rises, and the climate becomes cold. Those animals that have been well adapted to the warm, moist conditions are in hard case to survive. Many must perish. Lucky are the animals that now have variations which fit them somewhat better for the struggle with a harsh environment. This five-minute period[1] causes rapid evolution of new types. A chart of the animals through the ages widens

[1] The Permian.

out suddenly at this section into many kinds of short-legged, lizard-like reptiles. During the thirty-six minutes of this picture that we have seen—and during a whole previous reel that geologists can never see—life has been developing, and has progressed only as far as a big lizard. It is the early stages of any development that require time.

From now on [1] the changes of the land will be quicker and seem more significant. During the last six minutes it comes back to almost its present shape, and remains so. In the last quarter of a minute of the performance you see a spectacular ice-sheet come down jerkily below the southern boundary of Canada, and then retire. It was this that left the hills of pebbles which were spoken of at the beginning of the chapter.

And man in this picture? He was on the globe during the last second or two; civilised man has been here a tenth of a second.

A few views of the animals during those last twenty-four minutes would furnish entertainment. For fourteen minutes we could watch the reptiles increase in size, till some achieve a length of a hundred feet; and some grow heavier than four big elephants. They walk principally on their massive hind legs, which are midway between the long neck and the tapering end of the long tail. There are many other types of these "dinosaurs," and all varieties of other sorts of large and small, smooth or horned, lizard-like animals. It is the age of reptiles. From one species of these the birds developed, from another the earliest mammals. Other reptiles remained reptiles, and are with us to-day—crocodiles and turtles and snakes. And all the other reptiles? They died out.

There could be a picture of the progress, during the last six minutes of the reel, of a little animal only a foot high that walked on five toes. Its four side toes

[1] That is, after the Palæozoic.

grew smaller; its middle toe grew longer and longer; it increased in size until it was five feet tall, and became the modern horse. The palæontologist has been able to reconstruct other histories, quite as remarkable, of insignificant animals that developed during these same periods into the camel and the elephant. The stages of their growth are in the rocks, as surely labelled and dated by accompanying fossils as if they were classified for us in a museum. Yes, they are more reliably recorded; for naturalists make mistakes, but nature never does.

When any man has learned the alphabet of the fossils and is familiar with its grammar and idiom, he reads with assurance the history that has been preserved in the volumes of stone. It is written in the language of the Evolution Theory—more consistent and indubitable than any chronicles that come down to us in Latin or Greek characters. It reveals how every form of life descended from some earlier and simpler form.

The whole of the evidence in the rocks is vast beyond comprehension and makes bewildering demands on our mind. To any reader who knows no more of it than I can compress into this chapter it must seem somewhat unreal. As an indication of how actual and vivid it all is to men who spend their lives with it, I will give a description of a scene that has recently been uncovered in Southern California. If you could drive west from Los Angeles over a boulevard, step out of your motor-car at Rancho La Brea, and walk through the dry fox-tail grass to look into a certain excavation in a bed of tar you would feel the reality of geology.

All along the coast there are these out-croppings of asphalt, that has seeped through the shale and in some places formed deep pools of an extremely sticky substance, which can be dug out only by using heated shovels. The edge may be covered by soil and become hardened, while the centre remains tarry. Shortly before the Great War an excavation was made in one of these

pits, and there was discovered such a dramatic cluster of fossils as has never been seen elsewhere—sabre-tooth tigers and elephants and mastodons that had been caught in this death-trap, mired in it, sunk, and been perfectly preserved. If I should find my horse dead in quicksand, I should not know more certainly how he died than I know when I look into this pit how these tigers died. The men who study oil shales know, as a matter of practical business, in what geological period the asphalt was made. It is a certainty that during the last minute of our reel elephants mired down in the California tar and trumpeted their distress, and that they were heard by a kind of tiger that no longer lives on earth, and that the tigers were attracted, and mired down to their death. The contorted bodies tell their story as plainly as a charred corpse in a house of Pompeii, covered with volcanic ash, tells how the man died. The episodes of all the history of evolution in the rocks have come from scenes which, though not so romantic, are as unmistakable as that in the asphalt pit.

CHAPTER XII

THE EVIDENCE FROM GEOGRAPHICAL DISTRIBUTION

WHEN a certain English entomologist had studied a genus of beetles in Mexico, he prepared a chart showing where the different species live. "The study of the chart," he says, "gives clear ideas as to what the course of evolution has been." This little example will illustrate the experience of all modern naturalists when they map the locations of animals. If you could remove from their minds all knowledge of how species originate from previous species their charts would have no meaning; all the groupings of animals would be a disorderly jumble. But the combined labours of collectors fit together into an orderly whole of animal life when evolution is understood.

To every modern naturalist the term "distribution" is a pictorial way of saying "evolution." If we could look at the world of life through his eyes, we should see that any great class of animals, such as the insects, is everywhere over the globe; to make a chart of them would be simply to draw a complete map of the land surfaces of the earth, except for those few areas where there is no life of any kind. Even one division of this class, say the order of beetles, would be spread almost as widely. But any one family of this order, the leaf-beetles, for example, would be absent from some desert areas where other families have found a way to live. Any one genus of this family flourishes chiefly on one continent; it is to be found in only a part of the region that the family covers. Any one species of this genus is restricted to

a part of the territory occupied by the whole genus. When the range of any one species is thoroughly known, and its varieties charted, it appears that the species is most uniform and constant in the centre of the range, and that the distinguishing characters fluctuate more and more in proportion as the specimens are gathered from that centre.

The chart of the range of the species of any large genus of animals always shows a similar fact: there seems to be a centre of the most typical forms, from which many species radiate; and each species radiates from its own centre in varieties. If the naturalist assumes that each species is a group which developed from a preceding species, and that all the species of a genus branched out and pushed afield from some common ancestor, he can understand the distribution of animals. If he tries to imagine any other explanation of the locations of the different groups he comes to grief.

All the facts of distribution point toward one fact—that the species of animals always develop by migrating *continuously* from their centres. Just as the evidence from the rocks shows that all organisms have developed continuously in time, from one age to another, so the evidence from distribution shows that they have spread by steady advance from a centre where they originated. The chapters on classification and structure will show other phases of the evidence that life is always *continuous* in its lines of descent and location and classification and structure. The central truth of all the evidence in Part II. is that organic life, from whatever point of view we examine it, appears as a *continuous* whole. We cannot explain such a many-sided truth except by the theory that every form descends from a previous form.

If a zoologist finds some specimens of a certain species in Kent and some specimens of the same species in Cornwall, he cannot conceive that they are unconnected. All the evidence of distribution declares that the species must

live—or that eggs must have been transported, or that individuals must at some time have lived—continuously all the way from Kent to Cornwall. There is no evidence that the same species has ever originated in two places; it has only one origin, in one place, at one time; and from that origin it has spread out as far as it could go. And as a species spreads from its original centre it tends to alter, adapting itself to the new environments that it comes into. The whole theory of evolution would receive a severe shock if the facts of distribution did not always indicate that development has been continuous in time and place.

An illustration of the evidence that comes from distribution is seen in an exhibition of snail-shells that were collected in the island of Tahiti. The genus to which they belong has various species on many islands, but the five species in the exhibit are found only on Tahiti. Each of these appears as a pushing, branching, varying group of forms. No. 1 has pushed into almost every valley, and nowhere varies much in its white colour; whereas No. 2 is confined to one valley. No. 3 "has recently extended its range and differentiated into four varieties." No. 4 "has recently migrated and differentiated into varieties." Eight varieties of the wide-ranging No. 5 have been found. If these descriptions of what the shells have been doing were the fancy of some one collector we should pay no attention to them; they would mean nothing. But the same kind of description comes nowadays from all students of all kinds of animals everywhere.

Another graphic display of distribution is a large map on which are the skins of eleven species of striped ground squirrels. The great family which embraces all the squirrels is world-wide, but this genus on the map (*Eutamias*) ranges over only part of a continent. Each species is limited to a part of the whole area of the genus. When a scientist sees the large dark pelt of one species

change through a series of species across the map to one that is light-coloured and small, he reads a record of branching out from a parent stock and of altering to adapt to the new environments that were met as the genus spread. Every chart of every successful genus always reveals the same fact. When specimens are arranged according to where they live they present a series of graded forms, as if their genus were a source of variant life that was for ever trying to propel itself farther away, and that altered as it moved.

"Farther south," says one naturalist's report, "the species degenerates in size and is obscurer in colour." That matter-of-fact statement would have been queer jargon to Darwin in his boyhood, for it represents a group of forms as a fluid, fluctuating mass that changes while it grows toward a new habitat. But to the Darwin of middle life it would have sounded like a perfectly natural description, because a species at one end of a wide range is bound to be different from what it is at the other end. "In different localities," says the naturalist, speaking of another species, "it tends to the development of distinct local forms." Every study of distribution, of any plant or animal, shows the same tendency.

We have been attending to some petty examples. Take a very large one, as stated by Professor H. F. Osborn in 1900: "The fact that the same kinds of mammals and reptiles appear simultaneously [*i.e.* during the same geological periods] in Europe and in the Rocky Mountain region is strong evidence that the dispersal-point is half-way between." He predicted that such an origin would be found in Asia, and he named the fossils that must some day be searched for there. In the spring of 1922[1] an expedition to Mongolia began to find them, and in generous measure. When any theory of distribution has produced such successful prophecy as that it is well tested.

[1] Still more striking discoveries were reported in 1924 and 1925.

The greatest test of the theory is on the islands. Some of these are very close to a mainland, and some are very remote ; some have been separated very recently, and some for several geological periods, and some never were connected with other land ; some could be reached by immigrant animals of certain sorts, but not by other sorts ; they might preserve old species with little change or they might force old species to develop new adaptations. Thus they are like experiment-stations established in the ocean to give proofs of whether or not all species develop by continuous descent and in continuous lines of migration. If evolution were not true, its falsity would be sure to appear in some of the facts of animal life on islands. If it is true, then the following conditions would have to be found :

1. There would never be upon an island an animal whose ancestors had not reached the island.

2. In proportion as islands are farther from a mainland, or have been longer separated from it, the animals on them should be more different from those of the mainland.

3. But in some cases (for example, if some fierce competition of the mainland were removed on the island) we should expect to find that species had altered less on islands than on the mainland.

4. The kinds of animals would, in a general way, be numerous in proportion to the ease with which they could reach the island—for example, by flying, swimming, being borne in currents, being drifted by gales.

The facts of the distribution of animals on islands are in accordance with those conditions, as the following descriptions will show.

The Isle of Wight is detached from the mainland by only three miles of water, and the separation was made in very recent times. Hence we should expect that the animals and plants on it would be only very slightly different from those on the mainland. That is the fact.

When it became an island it was stocked with the same species that were on the Hants shore; and it has been so close to that shore that there could be much migration. There has been little time for new varieties to develop, and there has been only partial isolation from the life that swarms on the mainland.

The Bermuda Islands, eight hundred miles from a mainland, are low-lying limestone hills surrounded by coral reefs, a small, remote bit of land that has long been separated by hundreds of miles of water from the nearest Bahamas. Here we should expect to find the animals very different from those of the nearest Atlantic coast and somewhat different from those of the Bahamas. Such is the case. There is only one backboned animal which is native, a lizard that is found nowhere else in the world. Yet among the birds there are no peculiarities—no species that is not found on the mainland. Among the shell animals and insects, however, there are extraordinary differences—a great array of peculiar species. A zoologist who reasons about this problem of distribution asks, "Why should birds be just the same as on the mainland, while the reptile is a solitary curiosity and the shell animals are widely different?" If he could find any sensible explanation that did not depend on the evolution of species he would become famous; and there are hundreds of eager scientists who would be glad to work unremittingly many years for such a reward. But no zoologist ever wastes a precious hour on such a mad venture. He would have a better chance of finding out how to control thunderstorms than of finding a non-evolutionary clue to the assemblage of animals in Bermuda.

If every species has developed from a previous species by gradual alteration, and if every species is a varying group of life that is always prone to adapt itself in old surroundings or in new ones, then there is no mystery about the life of Bermuda. When the large continental

island east of America, "Antillea," was broken up into fragments during the last great geologic era, the northernmost bit that became Bermuda was stocked with the same genera that had populated the whole of Antillea, but that had varied a good deal since Antillea was, long previously, separated from the main continent. Then the species, in their isolation, entered upon a period of separate development. Some kinds of animals had been sparsely represented in this northern tip: lizards had been so scanty that only one species has survived to our time, and it has altered to a unique form. Of the abundant shell-fish many have remained practically what they were; many have branched into varieties; many have changed so far as to become new species. The same history holds for insects. For many animals Bermuda has been an isolated home: they could not leave it, and others of their kind could not reach it. But many shell-fish and insects and seeds have from time to time been brought from the south-west by gales and the ocean currents, and have thus replenished the local types. No snake or warm-blooded animal ever has survived such a long ocean journey to propagate its kind. As for birds, they have no more been cut off from Bermuda than they have been from the mainland; in their migrations they visit it regularly; and hence there has been no more reason for the development of a new species on the islands than there has been on the mainland. When geology and evolution are applied to these islands they furnish an understanding of the history of life there. Without evolution no rational history can be conceived.

The Azores are more isolated than the Bermudas. From water that is two and a half miles deep, in mid-Atlantic, they rise, not a thousand square miles of area, in complete isolation—eight hundred miles from the nearest point of Europe, nine hundred from Africa, and one thousand from North America. The life on these islands would be an impossible enigma without evolution. When

that theory is applied all can be understood. One kind of bird has long made the Azores its home, and it has become a unique species; but otherwise the birds are not peculiar. Most of the insects and shell-fish are like those of Europe; some have been much modified; all could have been immigrants borne by the accidents of storms and currents. No back-boned animal without wings is to be found there except those that have been brought by man. The islands have been almost entirely stocked with European forms of life, some of which have altered into new varieties and species.

It will be safe to say at this point that for sixty years there have been sagacious zoologists who wished to find some problem of island distribution that evolution could not solve. We laymen are almost sure to suppose, even after many repetitions, that "the scientists" have determined to support their pet theory and to adjust all the facts of island life to fit it. Doubtless some of them have had that attitude. But all the while there have been many more ready to challenge and oppose the theory. During the sixties most of the older naturalists were in that camp, and they bent their energies to show that evolution was not necessary to unriddle the Bermudas and the Azores; they invented "land bridges" and "dying out of species" and other possibilities to account for the facts. No modern geologist can find any support for their theories. No modern scientist knows of any way to understand the species of the Azores except as a gradual change of species into other species.

If a summary is made of all the facts known about the distribution of life on volcanic islands there is always confirmation of evolution; and there is never any crucial evidence against it. Men have seen islands so recent that not a vestige of any life was on them. On other very recent islands there have been seen specimens that have been carried from the nearest land and that are identical with the species on that land. No life has ever

been known to originate on a new island; it is always brought there as a continuation of previous species. Most of the immigrants to new land come from the nearest islands, or they are preponderantly from the mainland. There is never any species that might not somehow have arrived at that shore from another shore. When animals have been for some time in this new home—even for so short a period as a hundred years—their variations begin to take effect. Quite marked varieties have been seen in rats and pigs and rabbits, even during the three centuries that men have been able to observe such changes. Every peculiarity in the distribution of life on islands is consistent and comprehensible on the theory that no species ever originates without ancestry, and that most species tend to alter gradually and to send off new varieties, which will become new species if time is long enough. The composite picture of the distribution of plants and animals on islands is like a photograph of evolution. No details gathered from Hawaii and the atolls of the South Pacific and Iceland are discordant with the picture; all fit into place as part of a rational scheme of things.

A classic example of island life is that in the Galapagos, more than five hundred miles west of Ecuador. When Darwin landed on them, long before he believed in any theory of evolution, he was struck by the similarity of the life to that of the mainland. "Almost every product of the land and water," he reported, "bears the unmistakable stamp of the American continent." The conditions of life there were not very similar to conditions on the mainland; they had more resemblance to the climate and soil of the Cape Verde Islands, which are off the west coast of Africa. Yet the life of the Cape Verde Islands is African in character, and the life of the Galapagos is South American in character. A good observer cannot resist the conclusion that each group of islands has been stocked from the neighbouring continent. If he tabulates the evidence from all islands, he finds his

conclusion strengthened by everything that can be learned. Nothing has ever appeared that contradicts the conclusion. And another conclusion is quite as inevitable: most of these animals on the Galapagos are not now the same as when their ancestors migrated, but have altered so far as to have become new species. The evidence of distribution on islands always points one way.

The most remarkable confirmation is the great island of Madagascar. It is separated from Africa by only two hundred and fifty miles of water, and yet its life has much less resemblance to the African forms than the life of the Azores has to European forms—though the Azores are four times as far away from Europe. Why should evolution have anticipated that this would be the case? Because Madagascar has been separated from Africa vastly longer, and there has been time, in its large territory and differences of environment, to develop greater differences of form.

Madagascar has also preserved many types that are nearer to their ancient ancestors than any species that survived in Africa. It is like a museum where the naturalist may see forms that he could only have conjectured from the animals that now live in Africa.

The greatest collections of these zoological antiques are in New Zealand and Australia, where the animals that bear their young in pouches (the marsupials) are the dominant type. There was a time in geological history when the marsupials were common over the world; but they have become extinct (except for the opossums) everywhere but in New Zealand and Australia. There, cut off from the rest of the world, they have developed into flesh-eating animals that look like wolves, into gnawing animals of a rat-like appearance—in fact, into forms that outwardly resemble almost all the orders of placental mammals. The animal distribution in Australia is to the evolutionist what a discovery of an Egyptian tomb

is to the historian; it sets before his eyes the facts of bygone ages.

When geologists map the fossils, showing in summary form where the different kinds lived at different periods, the distribution in past eras tells him the same story that is everywhere attested on the islands at present. If a naturalist charts the habitats of birds or of wasps or of mastodons, he finds that he has made a sketch of evolution. If a botanist maps the pines or orchids or palms, the sketches of their distribution are sketches of evolution. Knowledge of distribution always strengthens the assurance that animals and plants have been developed by a process of evolution.

CHAPTER XIII

THE EVIDENCE FROM CLASSIFICATION

A CELEBRATED lecturer recently dared to make this statement to an audience: "There are myriads of living creatures about us, and yet not one is in transition from one species to another; every one is perfect." He will never know how untrue his declaration was. And even if he were curious about the facts of the case, it would be hard to show him his error, because the reality is so different from anything that he cares to talk about. In fact, he has stated a half truth that cannot be flatly denied, and it is the particular half truth that has caused the most scepticism about evolution. It is worthy of a full explanation.

If one were debating with him, the most telling retort would be to ask, "Did anyone ever see a stratum of rock rise from the ocean?" The answer is no. And yet any intelligent person must admit that strata have risen from the ocean; in some places we can see, with a strictly correct imagination, that rocks are now rising. It is so with species.

But comparisons do not prove anything. Put the question to a botanist: "How can you believe that one species changes into another if you have never seen such a change?"

He will answer: "Because we very seldom see a species stand still. Almost every species is varying right before our eyes. There are not many fixed species that you can describe and count on and distinguish from all other species. They change and blend and weave

in and out among each other so much that a botanist may find it hard to tell what any one species is. I might quote what an instructor of mine used to say about another topic: 'You won't understand it till you 've lived with it.' Select some small genus and live with it a while."

If you, unlike most people, care to spend a few hours with the genus of spruces, you can get at least an inkling of what the professor meant. You pull down your trusty *Britannica* and find eleven lines; only two species are named, and you are referred to the article on Fir. It appears that there are many genera commonly called "firs," and that two of them have always been much confused. But you at least learn that the genus you are trying to find is *Picea*, and you see the names of three species. The encyclopædia will do nothing more for you. So you turn to another work of reference. You learn that *Picea* and *Abies* have always been much confused, because the leading botanists have had different opinions about the best way to classify; but that the trees you know as spruces are now generally called *Picea*, and that the true firs are called *Abies*. That is queer, for the different kinds of evergreen trees have seemed to you "perfect species," not to be mistaken for one another. To refresh your memory you look up hemlock. Strangely enough it is to be found only under "hemlock-spruce," and is defined as "a sort of fir." Yet it is not of the genus *Abies*, but is of the genus *Tsuga*. If you now look up this genus you will be on the trail of *Pseudotsuga*, and will discover that "by Eichler, Bugler, and others it is united with *Tsuga*, and is variously called Oregon pine, Douglas fir, or Douglas spruce." Since life is short, you step back from this snare and stick to the narrow road of *Picea*. It appears that "Asa Gray and others included the genus under *Abies*, but that present usage calls the spruces *Picea*, which includes about twelve species." Now why, in the name of all that 's orderly,

should a botanist say "about"? Why shouldn't he count up exactly and say that there are eleven or fourteen?

Don't allow yourself to grow excited and to set your heart on finding out just how many species of *Picea* there are. For you never can know; nobody ever will know. The different forms of *Picea* could be lumped into seven species, or could be split into forty. A species is merely what a number of men think. Naturalists try, for their own convenience, to agree so far as they possibly can; but agreement by all classifiers is exceptional. Ask any botanist to name for you a species that is "perfect and distinct" from all other species. You might as well ask him where the Pacific Ocean ends and the Indian Ocean begins.

Thus you have one preliminary peep at what classification means. Look a bit farther. Read the descriptions of seven species of spruce: black, white, Norway, Himalayan, tideland of the Pacific coast, *engelmanni* of the Rocky Mountains, and *parryana*, "a rare and local mountain species of the western United States." If you look under "king-pine" you will find a ninth species, *webbiana*.

If you care to spend ten hours for a little more understanding of what classification means, you will discover that even a large inclusive genus of evergreens is not definitely marked off from other genera. It is hard to follow the ins and outs of the characters of cones and leaves and bark, so as to find some one way in which all of a certain large group can be positively distinguished. What holds good as a distinction between spruces and firs in Canada takes a backward twist in India. In the volumes of a big manual you can see how one botanist after another has spent perplexing years in assorting by some different sets of characters what previous workers had arranged in another series. A genus is not a firm, unmistakable type; it is like a fluid mass of life that flows among and interlaces with other related types.

And a species! It is a set of opinions formed by men who have tried to group the principal variations of a genus of forms that shade into each other. Every botanist who deals with the genus wishes that the divisions of it could be readily told apart, but he seldom encounters a distinct species. When he completes his chart of a genus he has made—against his will and with great labour—a display of variations that may be distinct at their opposite ends, but that blend where they meet.

Every person who is not a botanist takes it for granted that a spruce is a spruce. If he learns to tell a spruce from a hemlock and a balsam he is proud of his knowledge. Then some day he may have to cut and trim a number of young spruces and peel them for tent poles. They all look alike; unmistakably they are spruces, cut down within an area of a hundred square yards. But he learns that the bark of one comes off easily in long strips, and that the bark of another clings so that it can only be hacked off in bits. As he observes these trees in his neighbourhood he realises that they vary in the shapes of their tops, in the posture of the limbs, in colour. A dog would find that spruces differ in odour; a chemist would find that they have varying percentages of resin and sugar. Within the species, as it grows in one district, there are varieties which vary among themselves, until in the last analysis every tree is a unique individual.

Suppose that some wealthy young man became engrossed in the genus *Picea* and determined to make a fad of it for some years: suppose that he followed it from Newfoundland to Vancouver and around the world, taking his time to wander for many days in each locality, to make complete notes of variations in characters, to study constantly for some better scheme of classification of "about twelve species." After three years of travel and examination he spends a year in studying all the available literature of the subject and noting the discrepancies and ignorance of all authors—not one of whom

could spend so much time in this limited field. Now he is an expert. But realising that his knowledge is narrow, he studies general botany for three years more, specialising on the conifers and writing a treatise on a genus which is intermediate between *Picea* and *Abies*: "The Paired Species of *Tsuga*, a Study in Ontogeny to Determine whether *Pattoniana* is a Species or a Genus." You see, classification is such a difficult art, requiring such a long and severe apprenticeship, that no man is fit to determine species of spruce until he has proved by work in allied genera that he is a competent observer and that he has good sense in reasoning from his observations. If our friend can show some acuteness in his criticism of Professor Lemmon for erecting *Pattoniana* into a genus *Hesperopeuce* he will be listened to respectfully when he proposes a classification for *Picea*.

Just as he begins to prepare his monograph his eye falls on a startling piece of news in a scientific journal: a new field of research has opened for all students of conifers—the fossil *Bennettitales*. It flashes upon him that during ten years he has only looked at the surface, that there are facts of woody structure and mode of cone-bearing that may shortly upset whatever he publishes. He reads: "We find ourselves profoundly ignorant of the values of the characters of living plants for differentiating species. . . . There is difficulty is mastering the overwhelming mass of living species with which the fossils must now be compared." Still there is hope, for "In small genera of gymnosperms [of which the conifers are a part] the comparison may not be crushingly burdensome; Berry, Halle, Thomas, Bancroft, Antev, and others have already done pioneer work. . . . The detailed chemistry of different cell units is now gradually being correlated." For a few days his spirits are low, and he meditates a return to collecting postage stamps. But courage returns. Here is a fascinating vista of difficulties to overcome. Perhaps if he studies geology and palæo-

botany and chemistry and recent cytology for five years he may qualify to understand what Berry and Halle and the rest are about; he might even join in their exploration of the cells of conifers that lived ten million years ago. If he signs for such a cruise into the distant realms of species he will sail far beyond the bounds of this little elementary book on the outlines of the Evolution Theory. Of course, he will never return to classifying spruces; it is a job so far beyond present knowledge that it must be carried out by the next generation. He will go on and on toward an understanding of how no species is ever distinct, but is a branching group of forms, which branched off from an earlier stem, which grew from a still earlier stem. He will never see in future—no scientist ever sees—a species that is "perfect" and that stands still to let itself be classified as a fixed form of life.

You have seen one bit of an indication of what is in a botanist's mind when a breezy layman asks, "Have you ever seen a spruce change to a birch?" He can only smile—if he is good-natured enough—and say no. In that sense no student of plants has ever seen a species, in nature, change to another species. But such a question is the merest crude ignorance. In every other sense the botanist sees species changing. Species have hundreds of times been brought from nature to cultivation and have branched off into widely different varieties in a few years. When the ancestry of a species is traced back in geology, it is seen as a stream that alters from one period to another. A species is no more an everlasting creation than a mountain, and no more independent. Mountains and species are made out of previous mountains and species. A carpenter could as easily believe that houses are miraculously made out of wood that never grew in trees as a botanist could believe that any species was ever made without descending from a previous species.

The little experience with spruces could be duplicated with almost every genus of plants or animals. In some

cases, of course, there is a whole genus—yes, a whole family—that is quite distinct from any other form that exists—such as the tuatera lizards of New Zealand or the horned hog of India. There is a coon-like dog which is the only species of a genus, and an African hare that looks like a kangaroo, which is the only genus of its family. Such solitary types are just what we should expect to find sometimes if species change into other species; for there have always been groups that fell behind in the struggle for existence, that did not branch out into new forms, but gradually became extinct. The fossil record is full of such examples. There are in the world to-day many unique plants and animals that form the dying tip of a twig of the tree of evolution.[1] But otherwise, in the case of any type that is at all prosperous, there will be varying forms, impossible to reduce to order by any hard-and-fast lines of classification. Each type is like an area of life: in its centre it is decidedly different from the central forms of other types; at its edges it melts into surrounding edges.

When the classifiers of insects first saw the *Hypocephalus* of Brazil their brains would have reeled if they had known nothing of evolution. Here was a monster three inches long that was composed of family elements apparently as dissimilar as the characters of the cow, the dog and the squirrel. What could be done with him? If classification had to deal with fixed species there would be nothing to do except surrender. But if life is understood as a variant stream of forms this strange creature has a place in a rational universe, and comes to our museum as a witness to the course of evolution of beetles.

We have been long enough cramped in the limits of single genera. Take a flight into a wide region of classification and see what it looks like. One phylum

[1] See the diagram on page 159.

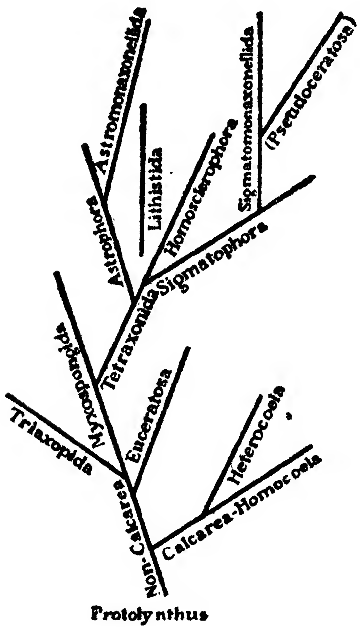
would serve as well as another. Try sponges. We could guess that there must be several kinds of them, because some are so soft and some are dark and coarse. Take three years off for the study of them.

They live on every seacoast. If you should decide to amuse yourself by classifying them without reading what zoologists have learned during the past century you would hardly make a beginning on the Gulf of Mexico in three years. By that time you might find out that you could not tell the difference between one sponge and a hundred sponges. It is not possible to decide surely on any dividing-line between an individual, all of whose cells work together as your own cells do to make one individual, and a colony of sponges which remain separate individuals. Some species are clearly of one type and some are clearly of the other ; but the two types blend.

Do you begin to weary of the "blending" of types? That is what every classifier wearies of. He cannot count on finding any border to any type that seems distinctive. This great tribe, A, is absolutely distinct from another tribe, B ; and you suppose for quite a while that they have nothing in common. But as you gain knowledge you discover that A is not fixed ; you gather specimens that form a continuous series, shading off from it toward the B type. The same is true of B : it shades toward A. They blend. In proportion as a group seems constant it is small and unsuccessful ; in proportion as you will find it widespread and victorious its forms are variant.

If you are sagacious and persistent you may learn after twenty years that there is a fairly well-marked division of all sponges into those that have limy skeletons and those that have flinty skeletons. The first group is small. You distinguish two kinds of them : (*a*) those that are lined with protruding cells ; (*b*) those that are lined, partly at least, with a smooth floor of cells. Even in this *b* group—much the smaller one—there is criss-crossing

with a third group, somewhat unlike either *a* or *b*, so that you are in despair about them. As for the flinty sponges, it will take you months to arrange the descriptions of them from your hundreds of note-books ; and when you have made a preliminary assortment on the basis of the cells with which they are lined it won't do at all. You see another possibility: perhaps you can classify them by the hardness and softness of their skeletons.



Chart, after Dendy, of the classes and orders of the sponges which have furnished specially interesting evidence of lines of descent from extinct forms. Compare this with the chart of a sub-genus on page 197.

If you persevere, reading the great treatises that scholars have made, and repeat your observations for several years, then you will understand that a fixed species hardly exists in nature, that a species is a compromise of opinions.

For a century men have been at work on sponges. So far the classifiers cannot agree on any mode of arranging the phylum. It would appear a wanton and meaningless mass of unreason if we did not understand that every form has branched from a previous different form and tends to continue to branch into new forms. With this knowledge for a clue, species are being assorted, and some time

they will be straightened out. As more is learned in other departments of zoology about the principles by which forms evolve the knowledge can be applied to throw light on sponges. No zoologist nowadays can conceive of classifying by any other clue. By it he is led to understanding; without it he gropes and stumbles in the dark.

A glance at the diagram of one classification of the sponges will illustrate how all classifiers conceive their business in the twentieth century. All life is thought of as a process of form branching from form.

The most significant item in the chart is the line marked Lithistida, which is left unconnected. When the chart was prepared fifteen years ago there was no way to determine whether this group was a "grade" or an "order," or whence it sprang. Instead of guessing about its origin the classifier indicated his ignorance.

Another view of the sponges will show another truth that classification regularly reveals—the relative largeness and smallness of the divisions. It is not entertaining; skip it if you don't like the look of it. For those who linger with it a minute I will explain that the steps downward in subdivisions are shown, from the greatest to smallest, by "One, I, 1, a"—representing respectively sub-phylum, class, grade, and order. The table on the following page shows only the large preliminary groupings, larger and more general than families and far above genera. The size of type indicates, very imperfectly, somewhat of the relative number of families in each division.

We have seen the tree-like appearance of the largest divisions of a great phylum. If we should take the next step down in classification, and should chart, for example, the *b* order of one of the grades, we should produce just the same kind of diagram of branchings; the big bare limbs of orders would each have clumps of branches—the families. And each of these families would send out clumps of smaller branches—the genera. Each genus, if

it was prosperous, would fork into many twigs—the species. And each flourishing species would have several leaves—the varieties. And the leaves might be sending forth buds—some sub-varieties.

Sub-phylum One
- a. order
- b. order

Sub-phylum Two
- I. Class
- II. Class
  - a. order
  - b. order
- III. Class
  - 1. Grade
    - a. order
    - b. order
    - c. order
  - 2. Grade (or this division may belong under Grade 1 as the d order)
  - 3. Grade
    - a. order
    - b. order
- IV. Class.

The diagram on page 197 pictures one man's classifying of a sub-genus of the big, black *Eleodes* beetles. This man would have been lost in the mazes if he had not known how to look for the course of development of each species and variety that he found.

Suppose that you had encountered Mr. Blaisdell as he returned from his six-month collecting trip over the plains, and suppose that you had asked him what a species is. Perhaps he would have sent you a copy of his bulletin, with this passage of the definitions marked: " Heterotype =an individual that forms an extreme of a specific or varietal series. Mesotypes =individuals connecting the extremes of a series. Amphitypes =individuals that simulate another species. Monotype "—and so on through

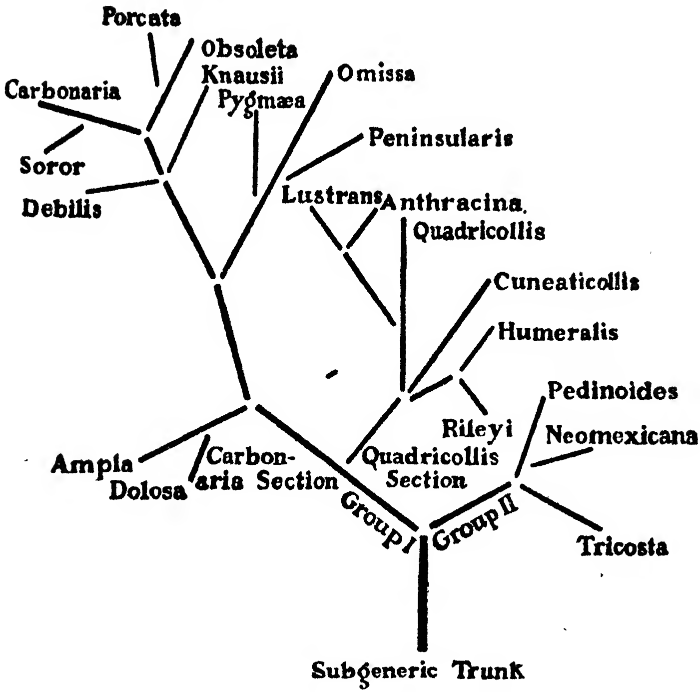


Chart of one section of a genus of large black beetles, after Blaisdell. It shows the same sort of branching that is seen in the chart of the whole vast phylum of sponges on page 194.

polytype, sexitype, and others. So absolutely non-perfect were the species and varieties that they cannot be conceived or in any way classified except by paying attention to that greatest truth of nature, that a species is a fluid form of life.

Pause a minute to take stock of the labour that Mr. Blaisdell put into determining the twelve species and eight varieties of this one part of a genus of beetles. And his labour was only a portion of the whole; for six

specialists had worked in the genus before him. Multiply the total labour of these seven men by eight thousand, in order to know how much effort it took to classify all the beetles. Multiply the product by some large factor, in order to have the sum of expert toil that has been spent upon classifying all animals. Double the product, so as to include all the classifying of plants. Then—and not till then—you will appreciate slightly the amount of evidence that is furnished by classification.

A classifier never can find a sharp line of demarcation between different groups. Between most species there are varieties that bridge the gap; between genera there are interlocking species; between families there are dovetailing genera; to separate orders so clearly that no family will bridge the gap is usually impossible. Classification always indicates that if our knowledge could ever be complete we should see that there never had been any gap anywhere, but that all transitions have been continuous, over bridges of variation that dropped out and disappeared from the record. "At this point," we are told by botany, "the distinction between flowering and flowerless plants breaks down." So deep a rift as that is well bridged over. The more men learn of fossil plants and animals the more they are taught that in past times there have been bridges between forms that to-day seem wide asunder. Life has been a whole, and there has never been any such thing as a separate species that was not attached through its branching ancestry to every other form that ever lived and branched upward from the beginning of life. A modern classifier can no more conceive of a species without ancestry than a biologist can conceive of an animal that had no parent.

I will close the chapter by a comment on the men who classify. So far as a rough count of the different sorts of sponges can be made, there are about two thousand five hundred species—only two thousand five hundred. It is well for us amateurs to try to stretch our

imaginations to the classifying of the sixteen thousand species of spiders. Perhaps we had bettbr excuse ourselves from trying to imagine the extent of the intricate labours of classifying the sixty-one thousand species of molluscs. Even if we were willing to strain our minds to the breaking-point, we could not conceive the total of patient work that has gone to the making of a chart of all the animals or all the plants. Of this vast domain of classification no modern scholar can know thoroughly more than one corner. The botanists and zoologists are a great corps of tireless and clever campaigners against the mysteries of nature. No one can command them ; there is no discipline. Some delve in coal mines for ancient ferns, some spend the years viewing grasshopper eggs under a microscope, and others dredge the depths of ocean or thread the tropical forests or study agricultural pests at home. No horde of self-willed barbarians were ever so free to spread where they like and think what they choose. Yet they all think one way and—whether they will or not—contribute to one fund of ever-increasing knowledge of one subject. Whenever they classify truly they extend the kingdom of evolution.

CHAPTER XIV

THE EVIDENCE FROM ARTIFICIAL SELECTION

THE kind of evidence that comes from artificial selection has been outlined in Chapter IX.—that is, the ways in which breeders select the variations provided by nature through a series of generations, piling them up as they occur in a desired direction, until they gradually develop a race that is widely different from the one with which they started. In this way many plants and animals have been slowly changed into forms so unlike their ancestors that they appear as different as a new species or even a new genus. Examples were given of two ways in which new varieties arise: (a) by selecting a series of slight variations, as in producing new kinds of pigeons or changing a small single daisy into a large double chrysanthemum; (b) by the sudden appearance of a new breed, as in the case of the hornless cattle or a new kind of peach. This sort of evidence has always been persuasive; it can be seen in operation; it indicates that all kinds of life, wild as well as cultivated, are variable and are prone to change to very different forms.

There is no need here to add pages of further illustration, but there is need of showing in Part II. that the facts of artificial selection are an important kind of evidence for evolution. I will give a few examples which supplement Chapter IX., and will then explain why this line of evidence is, if taken by itself, incomplete.

Darwin founded much of his reasoning on his knowledge of the breeding of animals and plants. Indeed, the evidence was so important to his theory that in 1868

he published two large volumes, *The Variation of Animals and Plants under Domestication,* as a sort of "case-book" for the *Origin of Species,* a storehouse of evidence that was too bulky to go into the *Origin.* So exhaustive was this great collection of facts that it is still cited as the principal sourse of information about artificial selection. I give below five quotations from the book, which show how differences brought about by artificial selection may be very great, very firmly established, and sometimes fitted to succeed in wild life.

1. The Japan pig is so distinct in appearance from all common pigs that it stretches one's belief to the utmost to admit that it is simply a domestic variety. . . . The modification of the skull in the most highly-cultivated races is wonderful. The whole of the exterior in all its parts has been altered: the hinder surface, instead of sloping backwards, is directed forwards, entailing many changes in other parts; the front of the head is deeply concave; the orbits have a different shape; the canines of the upper jaw stand in front of those of the lower jaw, and this is a remarkable anomaly; the knobs at the base of the skull are so greatly changed in shape that no naturalist, seeing this important part of the skull by itself, would suppose that it belonged to the genus of pigs.

2. The Niata cattle of South America have a forehead that is very short and broad, with the nasal end of the skull curved upwards. The lower jaw projects beyond the upper. Even the connection of some of the bones is changed. Scarcely a single bone presents the same shape as that of the common ox, and the whole skull has a wonderfully different appearance.

3. In the genus *Auchenia* there are four forms—the Guanaco and Vicuña, found wild and undoubtedly distinct species; the Llama and Alpaca, known only in a domesticated condition. These four animals appear so different that most naturalists, especially those who have studied these animals in their native country, maintain that they are distinct species. . . . Now

that we know that the domesticated species were systematically bred and selected many centuries ago, there is nothing surprising in the great amount of change which they have undergone. (Rohilkhund)

4. The humped cattle of India have run wild in certain parts of Oude and Rohilcund, and can maintain themselves in a region infested by tigers. They have given rise to many races differing greatly in size, in the presence of one or two humps, in length of horns, and other respects. . . . There are magnificent wild bulls on the bleak Falkland Islands in the southern hemisphere.

5. We must not overrate the amount of difference between natural species and domestic races; the most experienced naturalists have often disputed whether the races are descended from one or from several aboriginal stocks, and this clearly shows that there is no palpable difference between species and races.

The statement that "there is no palpable difference" between the results of artificial selection and of natural selection may be misleading. For it is a fact that no artificial species has been produced which cannot breed with other species descended from the same stock; and that means that in the brief time of man's selection no such deep and wide separation of types has been made as nature has created. Artificial selection is by no means a proof of natural selection; it is only an index to a strong probability.

Yet some of our domestic races are so ancient, as human history goes, and so thoroughly distinguished from any other forms existent in the world, that they seem to justify Darwin's emphasis. No one has ever seen a wild llama; we know that it has been domesticated in Peru for four centuries and that it was probably derived from the wild guanaco, but it exists now as a separate species. The Arabian camel has never been seen except as an animal domesticated by man. Maize has never been seen wild, and no ancestry is known for it. The

same is true of wheat. The differences between these results of artificial selection are certainly not "palpably different" from the species in nature.

Certainly none of the hundreds of practical men who study scientific agriculture can tell the difference between artificial and natural species, nor are they much interested in the difference. They all work on the supposition that the variations and sports in nurseries are of the same kind as those that occur in nature, and that the new varieties they produce are not palpably different from what nature has produced through all the ages. If sports from buds of sugar-cane and potatoes are so important in artificial changing of species, presumably the same sort of sporting has been a factor in nature's evolution. If the Seneca cherry of 1923 sprang into existence with new qualities—ripening early and having a spicy flavour—presumably such sporting seeds have had their share in causing nature's results. When an experimenter gradually develops a tobacco leaf that has only half the ordinary percentage of nicotine, he supposes that he is dealing with the same sort of mechanism which has caused tobacco and potatoes to branch from the common ancestry that every botanist knows about in nature. Of course, the experimenters may be wrong; but thus far no one has made any progress in discovering a difference between their results and nature's results. All men who collect and direct the variations of plants and animals suppose that their work is evidence for the Evolution Theory.

The strongest part of the evidence will bear re-statement in this chapter. If all artificial selection dealt only with domestic plants and animals the evidence would be weak. The fact is that all artificial selection begins with a wild species. In recent years many experiments have been made with plants that were never domesticated, and it appears certain that, if an experimenter is patient enough and has enough time, he can always discover variations to work with. It is

believed that every wild plant, and presumably every wild animal, could be developed gradually by artificial selection, into a form that is very unlike its present form. It would seem that artificial selection, however violent and abnormal it may be, is simply a use of the machinery of natural selection. Artificial selection may pull the wrong levers and may spoil the engine, but it indicates that the engine of natural selection is there.

CHAPTER XV

THE EVIDENCE FROM THE STRUCTURES OF ANIMALS

As a frontispiece to this book is a chart of the supposed course of development of animal life, from one-celled creatures to mammals. The makers of the chart would wish us to emphasise "supposed" while we study the branching lines of their exhibit; for they know better than we how mazy and back-tracking the paths of evolution have sometimes been and how puzzling is some of the scanty evidence.

On the other hand, they would wish us to know that in many ways the evidence is copious, and that it is extremely probable that their exhibit represents the main lines of evolution correctly. The principal parts of it were known fifty years ago, have been subjected to the severest criticism, and have stood the test. It is likely that the improved chart which can be made fifty years hence will differ only in some details. And the men who planned this diagram of life would wish us to understand something of the vast labour that has been necessary, by thousands of scientists in many departments, to secure the knowledge which made their chart possible. There is no guesswork in it. It represents keen observation and close reasoning.

The principal value of this graphic exhibit is to show us that the different sorts of animals do not have other sorts for "ancestors." The worms, for example, which are placed higher in the chart than the jelly-fish, are not "descended from" jelly-fish. The fact seems to have been, as the chart shows, that the different forms of life have

kept budding off into branches, which have divided into further branches. The squirrel, perched at the top, did not "descend from" some fishes that are below him; he is one of the latest twigs that come from a branch that came from a limb that grew from the common trunk. If human beings were to be placed in the chart they could not be shown as descendants of any animals now living, but only as a twig from the "primate" limb of that common branch from which all mammals spring. All animals must have a common ancestry, but seldom is one kind known to have sprung from another kind. Though it is commonly said that birds developed from reptiles, it might be truer to say that birds and reptiles have descended from some common stock.

The bottom of the trunk is labelled "Protozoa"—that is, one-celled animals. Science does not know anything about the roots of this tree—the origin of life—and probably never will know anything. It does not know, with mathematical assurance, that the earliest form of life was one-celled. But it finds all the evidence pointing in that direction, and makes the supposition until some contrary evidence appears. Science does not know positively that the first step of evolution was when two cells varied in such a way that they could live to better advantage in partnership; but science finds indications that such was probably the first step. Science supposes that, by a series of variations, many cells came to live in a partnership, forming a sort of colony. It is likely that these cells varied in diverse ways, so that some became better adapted for obtaining food, some for digesting it, some for distributing it. When these several sorts of cells had become much differentiated they were no longer able to live separate lives; each sort was dependent on all the other sorts; and thus the earliest many-celled animals are supposed to have evolved.

That sounds somewhat fanciful. Perhaps the idea would have remained a pure speculation if we had never

known anything about sponges; but among these we can see many stages of just such a process. There are sponges which seem to be mere colonies of similar and independent cells; other sponges in which the cells are highly differentiated and utterly dependent. In this case, as in every other part of the evolution chart, the biologists have not built upon their imaginations, but have always laid foundations upon facts now observable in nature.

Above the sponges the chart shows a branch of such salt-water animals as jelly-fish and sea-anemones. At this point the needs of saving space and avoiding complexity have made the diagram misleading; for the jelly-fish have continued to prosper ever since their ancient beginnings, and their line deserves to be extended to the same height where birds and frogs are displayed. A complete chart of evolution would show, from bottom to top, in what geologic period each type of animal arose, and would continue its line upward till it became extinct or reached the height of the present time. This chart, more convenient and graphic, indicates only how each type branched from the stem.

Two main branches of many-celled animals are shown. The one at the right has ramified into a far greater number of types than the other—from several sorts of animalcules and molluscs to crabs, spiders, and insects. Most of these are small animals; but one, the giant squid, is large enough to give a whale a tough fight.

At the base of the left branch are certain worms, and just above these some "radiating" forms, like starfish. From here up all the types tend to a "vertebrate" form—that is, having a backbone. They did not descend from worms or starfish, but from the same parent stock that gave rise to worms and starfish. So, as we look higher up, we are not informed that reptiles descended from fishes, but only that reptiles and fishes grew out of a common stem.

It staggers imagination to see the results of ages of the evolution of structures put thus abruptly before us in a disjointed series. We cannot see how the gaps could be bridged. When we learn that the scholars themselves disagree about particulars, and that sometimes they imagine linking forms which they have never seen, we are excusable if we give a verdict of "not proved."

Indeed, such an exhibit of successive structures through a long development may misrepresent evolution to us amateurs, for it implies that scientists have relied on a lot of clever conjectures. The truth is just the opposite. The unfilled spaces in the chart of evolution have always seemed more incredible to a biologist than they do to us. He knows how imitative nature always is and how the origin of a new bone is a prodigious work for her mechanism; he marvels at the ease with which students can take it all on trust and repeat off-hand, "Oh, yes, the leg evolved from a fin." It is the scientist who sees that the gaps are extraordinarily hard to fill. It has always been the keenest scholar who has felt most dubious about the successive steps of the evolution of a limb or other organ. He has never accepted surmises and guesses. He has had to be convinced by an unanswerable array of facts.

The study of structures is called anatomy, and the study of the similarities in the anatomy of different animals is called comparative anatomy. The more science learns about comparative anatomy the more it discovers those same *continuous series* that are so striking in the geological record and in classification. The student of anatomy knows of finely-graded forms from the limb of a lizard to the wing of a swallow, from the fin of a shark to the leg of a lion, from the smooth skin of a whale to the shaggy coat of a bear. The two ends of any such series of structures seem incredibly remote from each other. Every scientist of the nineteenth century, confronted with the extremes and asked to believe that

one evolved from the other, was infinitely more sceptical than you and I can be; for he knew how distinct they are in the departments of nature's workshop. Until he saw a demonstration of many actual steps in an anatomical series he never credited the evolution of one from another.

Imagine that in 1855 Darwin had said to some young man who was beginning the study of zoology, "The hoof of a horse must have developed by gradual continuous stages from the fin of a fish." Imagine the amazement of the young man. If he had lived till 1920, keeping himself abreast of the times and following each advance in zoology, he would slowly have learned—always against his will and his strongest prejudice—that there is no escaping Darwin's conclusion. It is now impossible for the comparative anatomist not to believe it.

An outline of what the young man would have learned begins in the rocks. In the geological period before the coal began to form a lizard-like amphibian one day walked on the hard mud of a river delta. His foot, about three inches long, was divided into two principal parts, but there was a bunchy third toe and a slight swelling corresponding to a fourth toe. One of his tracks was covered in such a way that it was preserved while the mud was transformed to sandstone, and after Darwin died it was discovered by a geologist. It is obviously the print of an amphibian's foot, padded and creased and unmistakable. It is the most ancient record ever discovered of any animal that went on feet. Above this stratum of rock there are, in all parts of the world, animals with five toes.[1] When these are classified in time order they are found to branch into many kinds, which can be charted in different lines of descent. One line comes down unbroken to modern turtles, another to lizards and snakes, another to crocodiles. Two other lines can be traced to queer species that are

[1] For the explanation of this great gap in the evolution of the foot see the next chapter.

all but extinct to-day, one of which is the duck-billed Ornithorhynchus of Australia. Many of the lines have completely died out. One developed into birds and one into mammals.

The young zoologist would have had small trouble in believing that all modern reptiles descended from ancient reptiles; a small part of the evidence would have convinced him completely. But birds! That would have been beyond belief for some years. Yet if he examined the structure of the winged reptiles that were found, and if he did not think that nature was making game of human beings, he would have had to believe that birds evolved from reptiles. The facts are patent in the museums of London and Berlin, where he could see animals the size of a crow that are as much like our feathered fliers as they are like the oldest lizards. Photographs can be faked, but these remains in the rocks cannot be deceptive—unless Satan has played a practical joke on the geologists. The wing of the most ancient bird was, in part, a membrane stretched along the side of the body, like the gliding-planes of the extinct flying reptiles; and it was also like the true wing of a modern bird, supported from the fore limbs and covered with feathers. Yet there were claws on the outer joint; and the head, skeleton and teeth were reptilian. No naturalist would have dared to imagine such a beast; nature made it and preserved two specimens for us to see.

"But what about the feathers?" the sceptic would have asked. "I can see that here really is a form midway between reptile and bird, but how could the scales change? You don't show me any steps in the evolution of such an extraordinary structure as a feather. Am I asked to guess that in some vague way each scale grew longer and frayed itself out into tens of thousands of perfectly adapted barbules?"

That is what he was asked to believe. Surely he might well have refused, since he had been taught to

think of a scale as a fixed kind of structure and of a feather as another kind of structure. But if we devoted a year to the study of each, we should find that some fish have scales that are "like hair or feathers,"[1] that the feathers of the cassowary are very simple structures compared with what we know as feathers, and that in young birds there is a coming and going of feathers such as we never see in any adult bird. We should learn that there is nowhere any hard-and-fast line to be drawn among all the forms that the coverings of vertebrates take: nails, skin, hoofs, scales, shells, plates, plumes, hair, down. We may go all the way along a series of structures from microscopic scales to the horny sections that make up a turtle-shell. Long familiarity with this blending of the different structures that grow from the skins of animals would make it hard for anyone to believe that they had separate origins; for they seem all related and essentially similar.

Thus the young zoologist would have grown to believe that undoubtedly birds evolved from reptiles. Not that the few indications here given would teach him—far from it—but that in his studious life he would encounter the hundreds of similar links in the chains of evidence that scientists are for ever discovering. Bare logic would not be effective; a few dozen probabilities would not persuade him. But the multiplied examples as the years went by would create an unshakable conviction.

As for the descent of mammals from reptiles, it is just a repetition of similar evidence from many series of structures: the order of the fossils and the rare animals still surviving in some corners of the earth give an indication that is irresistible. A student of comparative anatomy learns that there is no hard-and-fast line between reptiles and mammals—not even among the animals that now live. Perhaps to me in my ignorance there seems to be an

[1] Press report of William Beebe's expedition to the Sargasso Sea, March 7th, 1925.

unbridgeable difference between laying eggs and bringing forth young alive. But the biologist knows of a gradation from one kind of bearing young to the other kind: an egg may be hatched outside of the body, or it may remain within the mother till it is hatched, or it may remain attached to the mother till it has partly developed. Some fishes and snakes bring forth their young alive. The biologist gives the same name to the egg of a snake and to the egg of a sparrow and to the egg of a rabbit; he cannot distinguish sharply between the different kinds; he cannot conceive that they come from different sources; all his evidence shows that each mode of bearing young was developed from some preceding mode.

The early mammals were small. Apparently they developed in many races through long ages, picking a living as best they could by keeping out of the way of the huge reptiles that dominated the life of the world. If our zoologist kept pace with the fossil discoveries, he might have been convinced of this before 1880. But if any of his early doubts then remained he might have said, "It is too much to ask me to suppose that from a five-toed animal a few inches high there should develop an animal five feet high that walks on a solid hoof. There is no evidence for such profound alterations." Yet most geologists of that time believed that such had been the history of the horse, and they confidently expected that the proof would some day come out of the rocks. It came. There was a find of a small three-toed horse; and another that was smaller, with the side toes longer; and another that was smaller still. One day the news flashed over the wires that a four-toed horse a foot high had been found. Now a series of horses has been set up in a museum, showing graphically the actual progress of teeth and limbs as they changed and enlarged and took different proportions, from little twelve-inch *Eohippus* to a racing thoroughbred. Similar series are now known for camels and elephants.

The experience of this one zoologist represents the course of scientific opinion since 1860. Then evolution was seen at once to be a shrewd and likely hypothesis, but the gaps in the series of structures were so many and so great that few geologists could expect them to be accurately filled. Every decade has made some remarkable contribution to the evidence, and this steady accumulation which has always fulfilled prophecies and never disappointed them has converted the hypothesis into an axiom of zoology.

You may be wondering why a chapter on structure keeps talking about the geologic record. "Why," you ask, "must geology and anatomy be mingled in this way?" The answer is that the subjects are inseparable, as can be illustrated from the life of Huxley. He took a medical degree at the age of twenty, studied marine zoology till he was twenty-five, and at the age of twenty-seven, when he first met Darwin, had small faith in evolution. To him, as a student of structures, the gaps between the different classes of animals were too great to be bridged by any theory of common descent. He believed that even species were unchangeable forms of life. If he had never encountered any evidence outside his own field, it is probable that he never would have accepted Darwin's theory. But the fossil record was pointed out to him, and then he realised that the most incredible links of succession were actually to be seen in nature's museum. His judgment of structures had to yield to the knowledge that palæontology put before him. When he based his anatomy on these facts he found that baffling mysteries were cleared up, and that his study of structures could safely be built on the new foundation. And this, mind you, was long before the discovery of the reptile-like bird or the series of fossil horses. Huxley expressed his debt to geology thus: "The primary and direct evidence in favour of evolution can be furnished only by the fossil record."

I suspect that even the combination of palæontology and anatomy would not have been absolutely convincing to the young zoologist whose career we have been tracing. I can guess that, if he was at all like me, he would not have surrendered till he had learned of the entirely different line of evidence that is explained in the next chapter. The structures of animals, taken by themselves, might not have seemed a proof; they link together and complete the evidence that is in the rocks and the evidence that is in embryos. As you read the rest of this chapter about structures bear in mind that it is going to be supplemented in an extraordinary way.

Consider one of the simplest cases of evidence from structure. If we make a list of all the animals that have five digits at the ends of their limbs we have reason to suspect that they are all related. The way those five fingers or five toes appear in so many guises among the vertebrates, but nowhere else in the animal kingdom, is remarkable. How could it happen—as a set of unrelated accidents—that a panther and a mouse and a frog should have their feet built on the same five-toed plan? The front limb of a bat looks like a five-fingered hand with enormously long bones, one of which extends beyond the wing as a claw. A seal has no apparent use for bones in its flipper—for fish swim faster with no bones in their fins, and seven bones or seventeen bones would make as good a frame for a flipper. But, no—the seal has the same five fingers. The structure of a whale's fin is utterly unlike that of any fish; it is an arm—for there is a big bone at the top, then a pair of bones, then a wrist, and then five digits, one of which is shorter, like a thumb. It can hardly be an accident that so many back-boned animals have at the ends of their limbs a hand-like structure —no matter whether they live on land or sea—while no other phylum of animals has anything of the sort in its anatomy.

If this five-finger structure is studied, it is found to be wonderfully prevalent, though in all sorts of disguises and concealments. In the wing of a bird, though the limb structure has been modified almost beyond recognition, there still remain three little bones of the five of the original foot; and a rudimentary fourth one has been seen in embryos. In the bird's foot there are three prominent bones (the "metatarsals"), one small one, and the *stunted remnant* of a fifth.

Here we have opened up a whole new realm of structure. We wonder to what extent these *remnants* of bones could be found elsewhere among the vertebrates. They are a regular element of anatomy; so that if we know how to detect them we can add vastly to the number of five-fingered animals. In fact, the student comes to feel that any number smaller than five is abnormal, and must be the result of a loss at some time in the history of any modern species. He calls these undeveloped parts "vestigial," for they are vestiges or slight remains of what was once full-grown.

A whale is an exhibit of many remnants of structures that are of no use whatever to it, though they are highly important to the land-living mammals in which they are fully developed. Buried in the body of some species of whales, detached from the backbone, floating in the flesh, are some small remains of legs. They are at the point where a pair of hind paddles would naturally be. And in some snakes the same vestiges of legs appear. In the seal's body the corresponding bones have a strong development—into a regular leg-like series of thigh, lower leg, ankle, foot, and toes—to form the frame of the hind paddle. The only vestiges of hair on a whale are a few bristles near the mouth; the fur seal has the finest coat of hair in nature. The bones of the head of a whale are not the bones of a fish, but strictly those of the land-dwelling mammals; the skull of a seal is still nearer to the land-dwelling type. One kind of whale has

true mammalian teeth, but so vestigial that they never come through the gum ; the seal's teeth are strong and useful.

An ingenious naturalist who speculated on seals and whales could note that a seal, which spends much of its time on the land, is more land-like in structure (as shown in a dozen ways other than the hind limbs and teeth and eyes and ears), though it has much of the fish-like form. He could note that a whale, which never lives on the land, has almost entirely a fish-like appearance. Then he could hazard a guess that in some past age certain four-footed mammals found good hunting in the ocean, that every slight variation in structure which fitted them to move better in the water and to stay in it longer was useful and was selected to survive, and that thus there was a gradual adaptation to sea life. He could guess that the seals had gone one-fourth of the way toward complete sea life, and the whales about ninety per cent.—for the whales must still come to the surface to breathe air. If such a supposition about structures stood all alone in the world, it would be no more than a probability till other series of structures had been studied.

Some wings form such a series. It begins with squirrels which can make longer leaps because they are helped by an expanse of skin stretched along the body and held out as a gliding-plane between the legs. Many animals of very different kinds—from squirrels to fish—are helped in their motion by a similar device. Such a membrane is most completely developed among the bats, where it is supported on the excessively long fingers and is like a webbed hand. The extreme of the series is the feathered wing stretched along the whole arm. Other wings form a series that is an entirely different piece of architecture — a membrane supported on extended ribs. A third type of architecture is the wing of all the insects, which is not supported on limbs, but is an entirely different kind of outgrowth from a different element of the body.

When all the wings of animals are thus assorted into three groups of structure, it appears that the second is rarely seen. The first is the one that has been developed in two lines: the feathered arm-wing of the birds, the hand-and-leg membrane of the bats. The third has branched in the most extraordinary and successful ways among the wasps and flies and moths. Each type of wing shows a series. Each type of structure appears, when all are charted, to be a well-defined pattern which goes off at an angle from the other types. As we trace them back in time, we can see the similarity of their origins—that is, as outgrowths of the body-covering that were somewhat useful for aiding motion. We can see how each sort radiated farther from the other sorts in the course of ages, like the spokes of a wheel. But we never discover, in wings or in any part of anatomy, that the lines ever come together again.

If all the structures for seeing are classified and charted, they fall into three distinct types: the eyes of vertebrates; the eyes of molluscs; the eyes of insects. The first type of structure is found among all fishes and reptiles and mammals; every form is only a slight variation of the one architectural type. Nothing like the first type is ever found in insects or crabs or lobsters; nothing of the third type is ever to be seen in squids or snails. It appears that eyes, like wings, can be arranged in lines of structure that had similar origins—that is, in spots of the body that were sensitive to light. We can see how each type passed through a series of changes in a long course of development.

This fact of *series of structures* is observed in every phase of animal life. An armoured snail and a pulpy slug appear unlike and unrelated; but the student finds an unbroken series between the two extremes, through smaller and smaller shells, to a mere vestige, to a rudiment under the skin, to no trace at all. The heart of an ox is unlike the heart of a shark; yet, though they are such

different structures now, we must suppose that there is a line of descent to a common origin. So we could fill page after page—and great volumes have been filled—with these examples of the series that comparative anatomy has discovered. A dozen series would prove nothing; a hundred would make us suspect; a thousand would suggest a strong probability. When the students of anatomy find that in every respect the structures of all animals are always arranged in such ways that they could have been developed by inheriting variations they feel almost persuaded. After they have searched a hundred years for some other reasonable explanation of the structures and have found none, then they are convinced.

The whole study of structures fits in with the results of classification. An example is the eye of a hawk and the eye of an octopus. These animals had to be classified in entirely different phyla—that is, in the most widely separated groups, profoundly unlike in organisation. Yet their eyes were remarkably similar: each had cornea and lens and retina. This was perplexing; it seemed as if the evidence from structure was at odds with the evidence from classification, and the early sceptics about evolution made much of the argument. But their own reasoning proved that they were wrong: for it was discovered that the eye of an octopus, despite its similarity in appearance, is built by a different portion of the body, and is, in its origin, very different from the hawk's eye. As in this case, so in all others: the two kinds of evidence never have failed to support each other. The evidences of structure have never been made doubtful by the facts of the fossil record, but have in the most complete manner always been vindicated by the fossils. The three kinds of evidence, which are quite independent of each other, check perfectly.

The evidence from structure is the kind that is least understood by general readers. The ordinary way of

thinking about evolution is shown in the question, " How could a snake be changed into a dove ? " Each of these animals is at the end of an extremely long line of development. It is like a topmost twig of a branch on which some lower limbs have died and some have branched into varied forms. The evolution of forms never leaps across from the end of one twig to the end of another. Evolution is always a branching from below. If the student of structure follows *back, down* the tree of life, from the twig of snakes, he will come to a certain reptile stock ; and if he follows *down* from the twig of doves through the branch of modern birds to the limb of ancient birds, he will come to the reptile stock that gave rise to snakes. He does not *want* to do this ; he has no " will to believe " it ; he knows full well that many a part of the tree of life is undiscovered. But when he is thoroughly acquainted with all the lines of development of structure—from the short and obvious ones to the far-reaching and baffling ones—he has no option but to believe that every species of animal which exists came originally from a common ancestry in a very simple form of life.

Or perhaps it would be more correct to say that he suspends judgment until he learns about the evidence that is seen in the development of eggs, and then has no option but to believe.

CHAPTER XVI

THE EVIDENCE FROM EMBRYOS

A CRITICAL reader of the previous chapter may have noticed one point at which I seemed to slip hastily over a dubious description—the account of the earliest fossil footprint: "His foot was divided into two principal parts, but there was a bunchy third toe and a slight swelling *corresponding to a fourth toe*." The description passed quickly on to the five-toed reptiles, and then to the wide development of the five-toed foot among mammals. Thus it implied that reptilian feet were evolved through a three-toed and a four-toed form. No evidence was offered of any knowledge that this actually was the course of evolution.

No evidence could be offered in the previous chapter, because none has been found in the rocks. Yet no student of fossils doubts that there was such a course of evolution. If he had nothing to rely on outside of his own field he would be assured. But he has, from an entirely different source, a confirmation of a most impressive sort. It is a form of evidence that clinches all the other probabilities so completely as to seem almost uncanny when it is first heard of. It is furnished by the microscope, from observations of what takes place in eggs while they are hatching.

If you could look through a biologist's microscope at the developing egg of a little smooth-skinned, lizard-like salamander this is what you would see. The single cell divides into two; each of these two divides into two

others; and the process continues until there is a globule composed of a great number of cells. In its next stage the egg becomes a hollow globe. During the third stage one half of this globe bends inward, while the other extends itself around the bent-in part, and there results another globe with an inner and an outer layer. Now the embryo seems to be really under way. What follows has been described by Huxley in words of almost poetic enthusiasm: "The plastic matter undergoes changes so rapid, and yet so steady and purpose-like in their succession, that one can only compare them to those operated by a skilled modeller upon a formless lump of clay. As with an invisible trowel, the mass is divided and subdivided into smaller and smaller portions, until it is reduced to an aggregation of granules not too large to build the finest fabrics of the organism. And then it is as if a delicate finger traced out the line to be occupied by the spinal column, and moulded the contour of the body, pinching up the head at one end, the tail at the other, and fashioning flank and limb into due salamandrine proportions, in so artistic a way that, after watching the process hour by hour, one is almost involuntarily possessed by the notion that some more subtle aid to vision than a lens would show the hidden artist, with his plan before him, striving with skilful manipulation to perfect his work."

The embryo that Huxley described has at first only one toe. After a few hours this has swelled and shows three slight protuberances. These grow steadily more distinct, until the one at the end and the one at the right look almost like pulpy toes. Now the third toe (the one at the left) protrudes more and more, and later there is at its lower left side a fourth swelling; this becomes a well-extended fourth toe. Finally, from the lower left side of this fourth toe grows the fifth stubby toe. By this time the second and third ones have doubled their length, and there is your salamander foot with its five

digits.[1] The steps that were conjectured from the order of the fossils are here visibly reproduced in nature's motion picture, the development of an egg. A record in the rocks, which extended over millions of years of slow evolution from species to species, is here rehearsed[2] before our astonished eyes in a few hours. It is as hard to believe that the two records are not related as it would be to believe that Buckingham Palace and a photograph of it were accidental similarities.

What was conjectured about the evolution of the parts of animals, as this was judged simply from the comparison of their structures, can be seen as the minutes go by while we gaze at the building of a body in an egg. It was hard to see how an extra toe could "just somehow sprout" from a three-toed foot; and, indeed, we may never know *how* it could. Yet in the making of every individual salamander the fourth toe, and then the fifth toe, do sprout. The fact of millions of years of evolution of a race is written for our sceptical eyes whenever we watch the "invisible trowel" form a foot in an embryo.

More difficult still is it to imagine how in the evolution of such a complicated creature as a lobster the claws and feelers and legs were ever derived from a set of those simple and similar segments into which the primitive body of its ancestors was divided. Perhaps we shall never learn *how*. The fact that there must have been such evolution through long ages is brought home to the observer of the shaping of any embryo lobster. Let Huxley

[1] Description after Lull, from Rabl.

[2] This "recapitulation theory" was much overworked previous to 1910, and was extended with enthusiasm to help in the harder parts of classifying. Hence some distrust of it arose. This was put very strongly in the old *Britannica* article by Driesch, and echoes of the caution are heard in recent texts. "But," says Professor W. B. Scott, "none of the criticisms denies, and many strongly affirm, that embryology affords some of the strongest and most convincing evidence in favour of the evolutionary theory."

tell in his vivacious style what he once saw under his microscope:

> Our lobster has not always been what we see it; it was once an egg, a semi-fluid mass of yolk, not so big as a pin's head, contained in a transparent membrane, and exhibiting not the least trace of any one of those organs whose multiplicity and complexity in the adult are so surprising. After a time a delicate patch of cellular membrane appeared upon one face of this yolk, and that patch was the foundation of the whole creature, the clay out of which it would be moulded. Gradually investing the yolk, it became subdivided into segments, the forerunners of the rings of the body. Upon the surface of each of the rings thus sketched out a pair of bud-like prominences made their appearance—the rudiments of the appendages of the ring. *At first all the appendages were alike*, but, as they grew, most of them became distinguished into a stem and two terminal divisions, to which, in the middle part of the body, was added a third outer division; and it was only at a later period that, by modification, the limbs acquired their perfect form.
>
> Thus the study of development proves that the doctrine of unity of plan is not merely a fancy, that it is not merely one way of looking at the matter, but that it is the expression of deep-seated natural facts. The legs and jaws of the lobster may not merely be *regarded* as modification of a common type; in fact and in nature they *are* so, the leg and the jaw of the young animal being at first indistinguishable.
>
> These are wonderful truths, the more so because the zoologist finds them to be of universal application. The investigation of a polyp, of a snail, of a fish, of a horse, or of a man, would have led us to exactly the same point. Unity of plan everywhere lies hidden under the mask of diversity of structure—the complex is everywhere evolved out of the simple. Every animal has at first the form of an egg, and every animal and every organic part, in reaching its adult state, passes through conditions common to other animals and other adult parts.

It is impossible for Huxley, or for any man of mental keenness, to remain scientifically prosy when he states the fact that "every animal and every part passes through conditions common to other animals and other adult parts." No creature, in its early stages, has the outward look of its species—no, not even of its great class or sub-kingdom of animals; it is, so far as human eyes can see, at first a single cell, then a colony of cells, then a folded creature within an inner and an outer layer. It is true, in a very general way, that the embryo of every animal progresses up the scale of lower phyla to that point of advance where its limit lies; it emerges from the embryo to be a lobster, or to be a fish, or a reptile, or a bird.

It would appear as if nature could not originate any novel way of bringing an animal to maturity, but always had to follow the ancient process that she learned with great slowness in the course of long ages, while the higher races very slowly evolved. What she learned to do in the early eras of life she can now do with rapid ease, so that the lowest stage of any embryo is gone through with in comparatively short time; and as the limit of development of any embryo is reached its processes take longer. It would seem, if we continue this comparison with an artisan, that nature has learned many short cuts in the steps that took her so long while she fashioned the changing races. At any rate, our eyes cannot see all the steps as we observe a developing egg. The early ones seem hurried and huddled together; there seem to be quick jumps over gaps; and there are combinations of processes that probably never were in adults, but have been invented for use in embryos. Hence the history of all ancestors is not told fully and clearly in the egg. What can be seen, especially of the older parts of the line of descent, is a distorted and transformed history. But a history it is. Many of the chronicles of descent are there under some guise or other. The development of every individual is a partial and blurred "repetition"

or "recapitulation" of the long development of the race. Hence the facts of the development of embryos are expressed by the name "Recapitulation Theory."

What happens when a hen sits on her eggs, as every encyclopædia now tells us, is this: a fish-like animal appears, with gills and a long tail; then legs bud at four points, and there is a lizard-like animal; the fore legs develop rapidly into wings; the hind legs become chicken legs. The record of tens of millions of years in the rocks is rehearsed here in three weeks. When the ovum of a pig begins to develop it is hardly to be distinguished from the early stage of a chick, for it looks like a fish; then its legs bud—not pig's legs in appearance, with a cloven hoof, but legs that resemble a lizard's; the fore limbs and the hind limbs develop into pig's legs. The embryo of a rabbit seems to be a fish and a reptile before it becomes a rabbit. Every mammal, in its own life, lives rapidly through the stages that cover such stupendous ages in the rocks. If John is curious about his own evolution, he should read an encyclopædia article that describes the stages through which he himself lived during the first months of his life.

The revelation of race history that comes from embryos is of a kind that rivets attention. It is startling and romantic to the last degree. The nature of it may be put into graphic form thus: An English surveyor goes tapping about the hills with his hammer, never dreaming of evolution, and as he pieces together the facts in the rocks they spell out before his astonished eyes a history of an order in which animals succeeded one another while the different rocks were formed. In a laboratory of North-Eastern Prussia a Russian scholar works month after month with his microscope; through the lenses there swims into his ken, as the egg develops, the history of the same order of succession. The testimony of the rocks and the revelation from the egg coincide.

Long before the *Origin of Species* appeared the

embryologists had seen the stages of development in eggs. One of the greatest of them used to exclaim as he showed his specimens, "I have here the embryos of lizards and pigs and rabbits, but I cannot tell which is which. They are all alike." Until 1859 there was no meaning to these facts. Then embryology took a fresh start, and it began to contribute to evolution.

The first actual demonstration that embryos and rocks tell the same truth was not made until 1869. In that year a German named Waagen published his observations of three species of coiled ammonite shells. Waagen found in three successive strata the three species arranged, of course, in the order of their evolution. Many of the specimens were of half-grown shells, and of shells only in infancy. A study of some of the undeveloped shells in the top stratum showed that they resembled the mature shells of the earlier species in the stratum next below; and a study of shells still less developed proved that they resembled the oldest species in the lowest stratum. Nature had arranged in this series of rocks a display of embryology, a demonstration that every shell in its individual life had gone through just the changes that the race of shells had gone through in the three strata. No more precise or sensational sort of proof was ever known to science.

The life histories of all sorts of animals have been studied with most painstaking scrutiny. There have been able embryologists who would have given all they owned to prove that the development of an egg does not parallel the fossil record, and they have argued and protested with vehemence. So startling a correspondence between two such different departments of science is unique, and the reasoning about it has been subjected to a long and fierce test. The recapitulation theory has stood the test. No evidence from the microscope collides with any evidence from the fossils. In many striking and conclusive ways the microscope has shown zoologists

how to classify ; but it has never given evidence counter to the principles of classification. If the combination of the fossils and the embryos is not a proof, then the universe is a whirligig and man's reason signifies nothing.

It may perhaps be conceivable by some minds that the records of rocks and eggs merely happen to have a resemblance. Possibly some intellects can suppose that all nature was planned as a temptation, to deceive the minds of scientists by a coincidence that means nothing. We cannot prove that a Creator might not have paralleled the embryos and rocks in a fit of humour. Evolution cannot be demonstrated. But every modern scientist, aware of how serious and uniform nature always is, must reject any such evasion of evidence. There is nothing for any logical mind to do but to accept the Evolution Theory.

CHAPTER XVII

THE EVIDENCE FROM BLOOD

THE chapter on the structures of animals was limited to the large and noticeable features of the body, such as bones and organs. It could have been extended to all the minute portions, like the fluids and cells that carry on the life processes. For just as nature follows one architectural pattern for limbs and eyes in each sub-kingdom of animals, so for each small matter of physiology she keeps to a general similarity throughout the whole of a group. Take the blood as an example. We should suppose that the warm blood of a bird was more like the warm blood of a mammal than the cold blood of a turtle. But this is not so. For birds are of the reptile stock, and every corpuscle that carries oxygen to their tissues is made on a reptilian pattern—that is, it has a nucleus, and is a true cell. The full-grown red corpuscle in a mammal's blood has no nucleus. Hence a biologist could tell by a glance through his microscope whether a sample of fresh blood came from a lower vertebrate or a mammal.

The differences in the blood extend to very much finer matters than corpuscles. The chemical components are different. And they do not differ erratically, independently, but always in correspondence with the general structure of the phylum and class and order and family. If we had instruments fine enough to detect all these slight and orderly differences there is no doubt that a mere examination of a specimen of blood would show from what genus it came, and from what species. Every particle of blood is compounded by the recipe

that fits its particular species, a recipe that is unlike the formula for any other species. These distinct and precise differences that must be in bloods was somewhat understood forty years ago. In 1904 an elaborate treatise on the subject was published in England, called *Blood Immunity and Blood Relationship*, which explained a most accurate and far-reaching method in physiology.

The knowledge of blood relationships has furnished the latest kind of evidence for the detectives who seek the clues to evolution. It is evidence from an unexpected source, entirely independent of any knowledge that comes from other lines of research. The nature of these "blood tests" and of what they show may be briefly outlined as follows:

If some serum of the coagulated blood of a horse is injected into the veins of a rabbit, the rabbit's blood forms a sort of anti-toxin against the chemicals of the invading serum from the horse. If, now, some serum from such prepared rabbit blood is put into a solution with horse blood, there is a chemical reaction that is well known and unmistakable. But if the prepared rabbit blood is put with ordinary rabbit blood, there is no reaction. In other words, the blood that has bred anti-toxin against the horse serum is a very sure and delicate test for horse blood. The evidence, it should be noted well, is not from living cells or tissues or any form of life: it is from a very different source—from the field of chemical reaction.

The test works so perfectly for human blood[1] that it can safely be used in murder trials to determine whether or not a stain was made by blood from human veins. It indicates in a very detailed way that the relationship of man to other animals is what the evidence of anatomy and the embryo shows.

A long series of experiments has been made with

[1] In *Science* for May 8th, 1925, is an article by Landsteiner and Miller, of the Rockefeller Institute, confirming and extending the Nuttall tests in a remarkable way.

all sorts of combinations; the result is that "anti-blood tests" are found to be of varying intensity. For example: the rabbit's blood that is "anti-horse" will react against the blood of a mule or a zebra, but less strongly; it will react less strongly still against the blood of a cow or a pig. It is found to be generally true that in proportion as any animal is more nearly related to the horse in classification its blood gives a stronger reaction, and that as the relationships of different animals grow more and more distant from the horse the reactions from their bloods grow weaker and weaker. The chemical evidence is in close correspondence with the evidence from classification and structure.

In fact the anti-blood tests are now well enough understood and tabulated to be used as evidence in clearing up some doubtful points of classification. Anti-pig serum, for instance, will act strongly against the blood of any member of the pig family; it will act much less strongly against the blood of camels and llamas (about equally for these nearly-related animals); and much less still for a whale.

Blood tests have shown that birds are more nearly related to turtles than they are to lizards, and thus confirm in a most curious way what the experts in fossils had conjectured.

How to classify the horse-shoe crab has always been a puzzle. The study of embryos showed that it was more nearly related to the scorpions than to real crabs—an unexpected verdict. Hence the blood-test men must have felt some excitement when they had perfected their art enough to apply it to this peculiar puzzle. The blood test confirmed the embryos.

What fame would have come to these workers with serums if they could have produced evidence against the rocks or the embryos? Their experiments would have been proclaimed in every scientific journal, and the newspapers would have written them up. They could

have sold one hundred thousand copies of a book entitled *Darwin Overthrown by Blood*. But there was no such fame or wealth in store for them. They could do no more than add to the list of evidences which always grow stronger, never infringe on one another, and multiply one another's strength. Everyone who has ever learned something new about the life of plants and animals has always—whether he would or not—brought fresh witness to the Evolution Theory.

CHAPTER XVIII

THE FOSDICK IDEA

It is now an antiquated custom to quote some proof that the most devout minds may see in evolution a noble and helpful conception. But the recent activity of the late Mr. Bryan and the response to his efforts indicate that such a chapter as this one may still be advisable.

The testimony that the Reverend Charles Kingsley gave a week before the *Origin* was published might serve to epitomise everything that need be said on such a subject, or that has yet been said. He wrote to Darwin from the rectory at Winchfield to acknowledge the receipt of an advance copy. He addresses Darwin as "the naturalist whom, of all naturalists living, I should most wish to know," and says, "If you be right, I must give up much that I have believed and written." Then he formulates the way in which he thinks a divine should regard religion and science: "I have gradually learnt to see that it is just as noble a conception of Deity to believe that He created primal forms capable of self-development into all forms needful as to believe that He required a fresh act of intervention to supply the lacunas which He Himself had made. I question whether the former be not the loftier thought."

What Protestant has not heard of Henry Drummond? His *Natural Law in the Spiritual World* has been an inspiration to hundreds of thousands of Christians, and he accompanied the evangelist Moody in many of his revival services. "If God comes upon the scene at special crises," says Drummond, "He is absent from the

scene in the intervals. Is all-God or occasional-God the nobler theory? The idea of an immanent God, which is the God of evolution, is infinitely grander than the occasional wonder-worker who is the God of an old theology."

As for the Catholics, their church has never pronounced against evolution. Every priest has always been free to believe in Darwinism or not. To give a view of what Catholics have done with the freedom in recent years I quote a few excerpts from a letter to the *New York Times*, written by Doctor Bertram C. A. Windle, of St. Michael's College, University of Toronto: "The Church is neither committed to the crude and unthinkable Miltonic idea of creation, nor to the rigid 'special creation' view of Linnæus. This entails an idea of species which is increasingly difficult to hold. The Church has never expressed any opinion as to the method of creation. . . . From the time of St. Augustine of Hippo in the fourth century there has been a constant stream of suggestion that at the creation many, almost certainly most, living things were created, as he puts it, 'potentially,' and so as not then to appear, but only as an unfolded product when the time for them had arrived. Not, be it noted, by what is called very foolishly an 'interference.' The clockmaker does not 'interfere' to make the clock strike when we hear it chiming out midnight. He made it just so that it should strike at that time. St. Thomas Aquinas centuries ago, but also centuries after St. Augustine, mentions this thesis with approval; and in the best writings of to-day what the last important writer, Professor de Dorlodot of Louvain University (a palæontologist) calls 'the moderate view,' is adopted—a view which is exactly that which was defined by Darwin himself when he wrote of 'life with its several powers having been originally breathed by the Creator into a few forms or one, and that from so simple a beginning endless forms most beautiful and most wonderful have been and are

being evolved.' . . . Father Wasmann, S.J., the eminent authority on ants, and indeed on biology generally, when expressing his concurrence with this view says: 'My own conviction is that God's power and wisdom are shown forth much more clearly by bringing about these extremely various conditions through the natural causes of a race evolution than they would be by a direct creation of the various species.' . . . My second quotation shall be from M. de Dorlodot, because of the recency of his book and because it bears the imprimatur of the rector of his university: 'It seems to me that the more science progresses the more audible becomes the voice of nature proclaiming the glory of its Creator. And among the heralds whom nature has used to make her voice heard, even to the ends of the earth, I think it just to place in the first rank Charles Darwin.'"

I have called this chapter the "Fosdick Idea" because the thought in it has been most forcefully presented by the Reverend Harry Emerson Fosdick, who is a Baptist of the United States, a professor in the Union Theological Seminary, one of the best-known preachers of the day and one of the most effective in reaching young people, and author of several such devotional books as *The Meaning of Prayer*. If he is wrong, heaven help the church. I quote from the answer which the *New York Times* asked him to make to a communication that it had printed from Mr. Bryan, entitled "God and Evolution." Doctor Fosdick's article has been reprinted in several religious journals:

A large number of Christian people are quite as shocked as any scientist could be at Mr. Bryan's sincere but appalling obscurantism.

When he says, "Neither Darwin nor his supporters have been able to find a fact in the universe to support their hypothesis," it would be difficult to imagine a statement more obviously and demonstrably mistaken. The real

situation is that every fact on which investigation has been able to lay its hand helps to confirm the hypothesis of evolution. There is no known fact which stands out against it.

The Bible is for Mr. Bryan an authoritative text-book in biology—and if in biology, why not in astronomy, chemistry, or any other science, art, or concern of man whatever? One who is acquainted with the history of theological thought gasps as he reads this. One had supposed that the days when such wild anachronisms could pass muster were passed, but Mr. Bryan is regalvanising into life that same outmoded idea that the Bible is "the source of all science and arts including law, medicine, philosophy and rhetoric." Martin Luther attacked Copernicus with the same appeal which Mr. Bryan uses. He appealed to the Bible. He said, 'This fool wishes to reverse the entire science of astronomy, but sacred Scripture tells us that Joshua commanded the sun to stand still, and not the earth."

One who is a teacher and preacher of religion raises his protest against this use of the Bible because it does such gross injustice to the Bible. When one reads an article like Mr. Bryan's one feels, not that the Bible is being defended, but that it is being attacked.

The fundamental interest which leads Mr. Bryan and others of his school to hate evolution is the fear that it will depreciate the dignity of man.[1] Just what do they mean? Even in the Book of Genesis God made man out of the dust of the earth. Surely that is low enough to start, and evolution starts no lower. So long as God is the creative power, what difference does it make whether out of the dust by sudden fiat or out of the dust by gradual process God brought man into being?

[1] Anyone who cares to read an authoritative argument about this fear will not do better than to consult *Evolution and Christian Faith*, by H. H. Lane (Princeton University Press, 1923). Professor Lane has taught biology in two Christian colleges, has been for thirty years a devoted worker in a Protestant church, and wrote his book in answer to a petition from students who asked: "What effect has acceptance of the theory upon religion?"

If one could appeal directly to Mr. Bryan, he would wish to say: Let the scientists thrash out the problems of man's biological origin, but in the meantime do not teach men that if God did not make us by fiat, then we have nothing but a bestial heritage. That is a lie, which once believed, will have a terrific harvest.

The real enemies of the Christian faith are not the evolutionary biologists, but folk like Mr. Bryan who insist on setting up artificial adhesions between Christianity and outgrown scientific opinions. The pity is that so many students will believe him and will give up Christianity in accordance with his insistence that they must.

It was in the eighteenth century that God was thought of as the absentee landlord, who had built the house and left it. The nineteenth century's most characteristic thought of God was in terms of immanence—God here in this world, the life of all that lives, the sustaining energy of all that exists, as our spirits are in our bodies, permeating, vitalising, directing all.

Mr. Bryan proposes that we shall run ourselves into his mould of mediævalism. He proposes, too, that his special form of mediævalism shall be made authoritative by the State, promulgated as the only teaching allowed in schools. Surely we can promise him a long, long road to travel before he plunges our educational system into such incredible folly; and if he does succeed in arousing a real battle over the issue, we can promise him also that just as earnestly as the scientists will fight against him in the name of scientific freedom of investigation, so will multitudes of Christians fight against him in the name of their religion and their God.

THE END

Bibliography

Books in the first group are those most important for the layman who wishes to do some further reading of brief epitomes of evolution ; in the second group are some useful books of a more technical kind ; in the third group are certain books or monographs which are referred to in the notes of *Evolution for John ;* the fourth group names some texts that will give a non-scientific reader the fundamental facts of the different branches of biology.

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